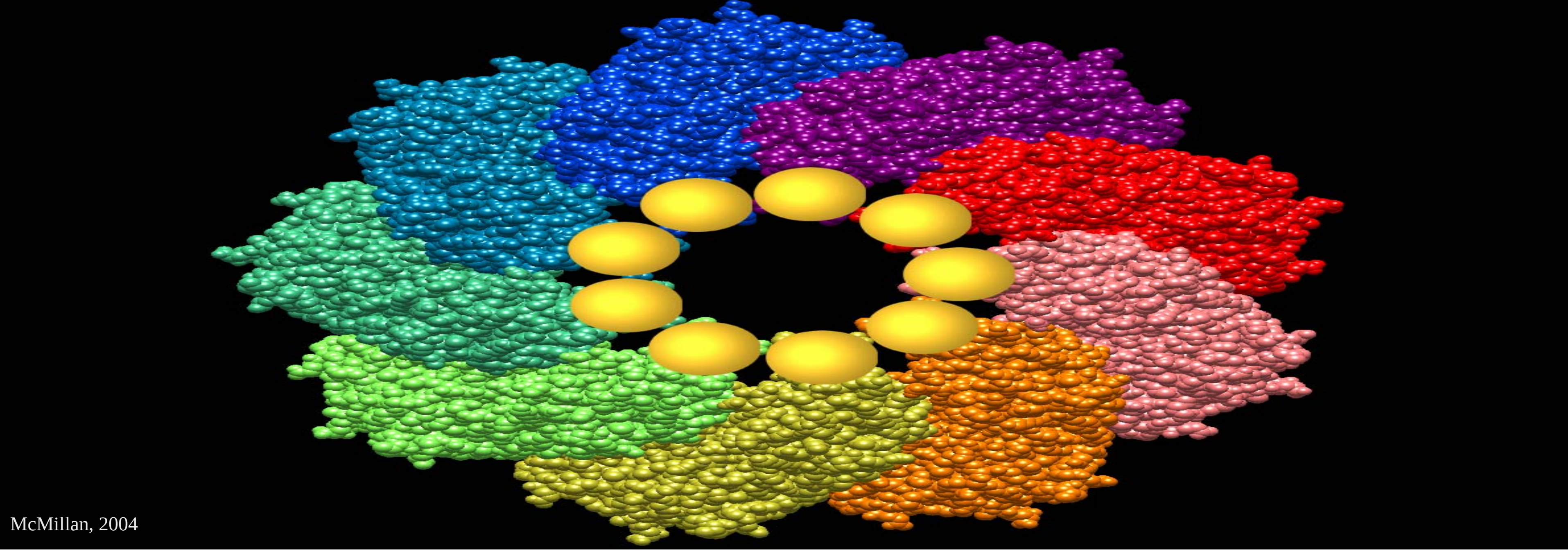


The Challenge of Transforming and Responsible Nanotechnology

Dr. M.C. Roco

Chair, U.S. Nanoscale Science, Engineering and Technology (NSET), NSTC
Senior Advisor for Nanotechnology, National Science Foundation

Presentation posted on **www.nsf.gov/nano**

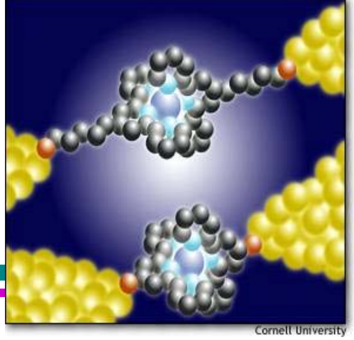
Columbia, South Carolina, March 3, 2005

Topics

- **Nanotechnology - transforming outcomes for economy, quality of life, education (first NNI strategic plan: 2001-2005)**
- **New frontiers for nanotechnology in 2005 (second NNI strategic plan)**
- **Societal implications: responsive to people needs and aspirations**

Nanotechnology

Definition on www.nano.gov/omb_nifty50.htm (2000)



- **Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure**

- **NNI definition encourages new contributions that were not possible before**

  - novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain

  - the ability to measure / control / manipulate matter at the nanoscale in order to change those properties and functions

  - integration along length scales, and fields of application

NNI - Why nanotechnology is important?

- **Reaching at the foundation of matter**

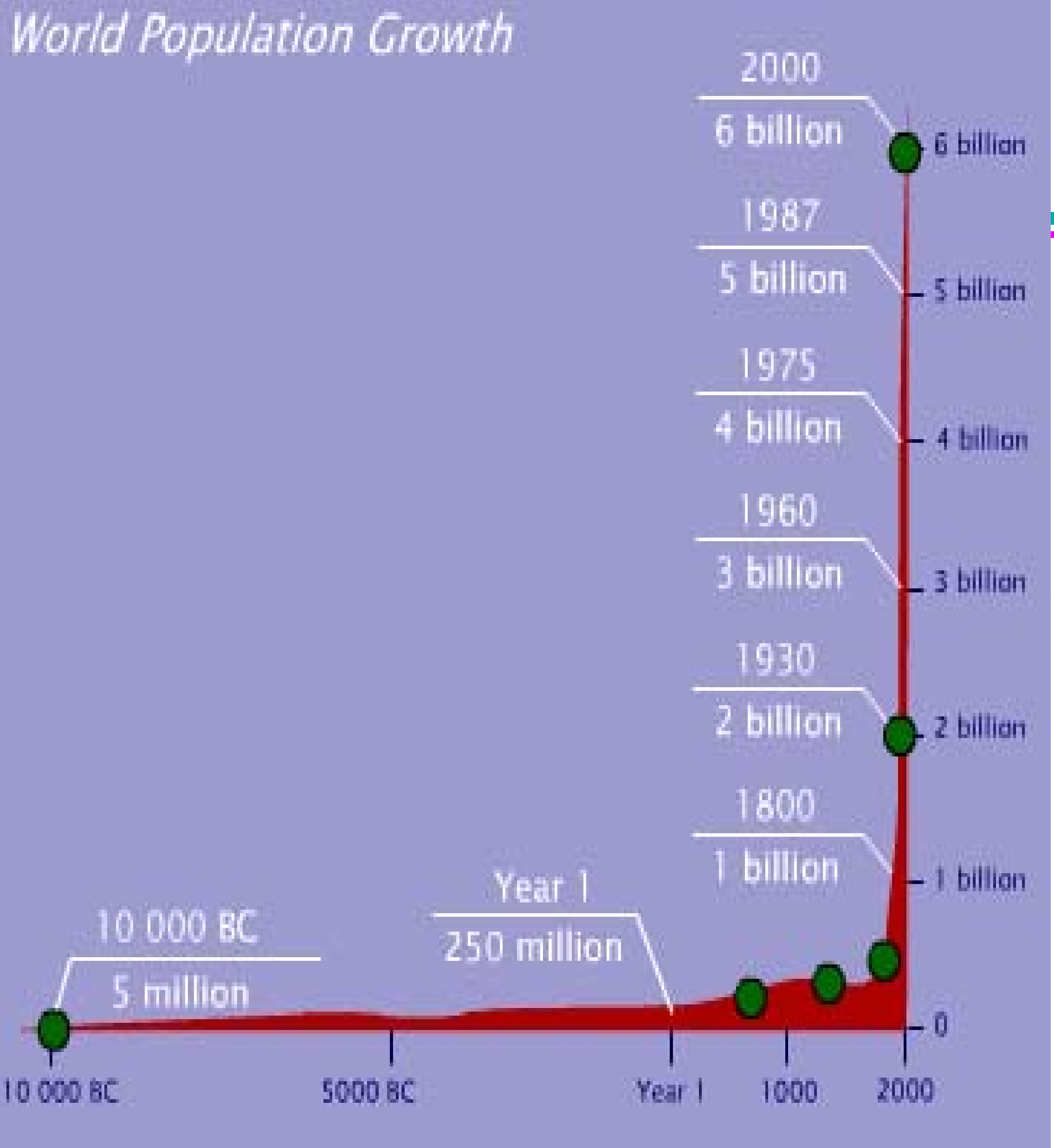
  Historical event in understanding, control and transformation of natural/living and manmade systems (natural threshold)

- **The long term societal implications**

  Improved knowledge, quality of life, and environment

  Create foundation for a new industrial revolution

- **Higher purpose goals than development of NT**
  - More basic and unifying science and education
  - Higher efficiency processes and novel products
  - Molecular medicine
  - Extend the limits of sustainable development
  - Increased coherence/integration of S&T policies



More people

9-10 billion by 2050

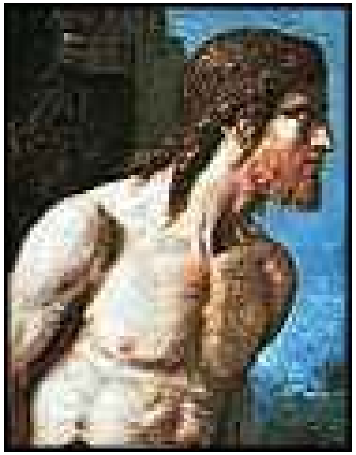
- Increased consumption of water, food, energy
- Changing environment
- Changing society
- Maintaining peace

NEED OF RADICALLY NEW TECHNOLOGIES

MC. Roco, 3/03/05

Chances and risks of technology

- <u>Human potential and technological development are coevolving</u>, and quality of life has increased tremendously with technological advancements



However, there is a perceived tension between the society and technology (maybe because significant changes, accelerated path, larger benefits & risks). Prometheus giving the fire: <u>"An eternity of torture"</u>

- <u>Technology implications are global issues</u> (human development, EHS, E-W & N-S balance) that need to be addressed together

NNI – promotes multidisciplinary approach, interagency and international collaborations

Nanotechnology development cannot be decided only by nanotechnologists

Nanotechnology will broadly affect society, from new products to art

TRANSFORMING SOCIETAL IMPLICATIONS
(Ex: worldwide estimations made in 2000, NSF)

- **Knowledge base**: better comprehension of nature, life
- **New technologies and products: ~ $1 trillion/year by 2015**
  (With input from industry US, Japan, Europe 1997-2000, access to leading experts)

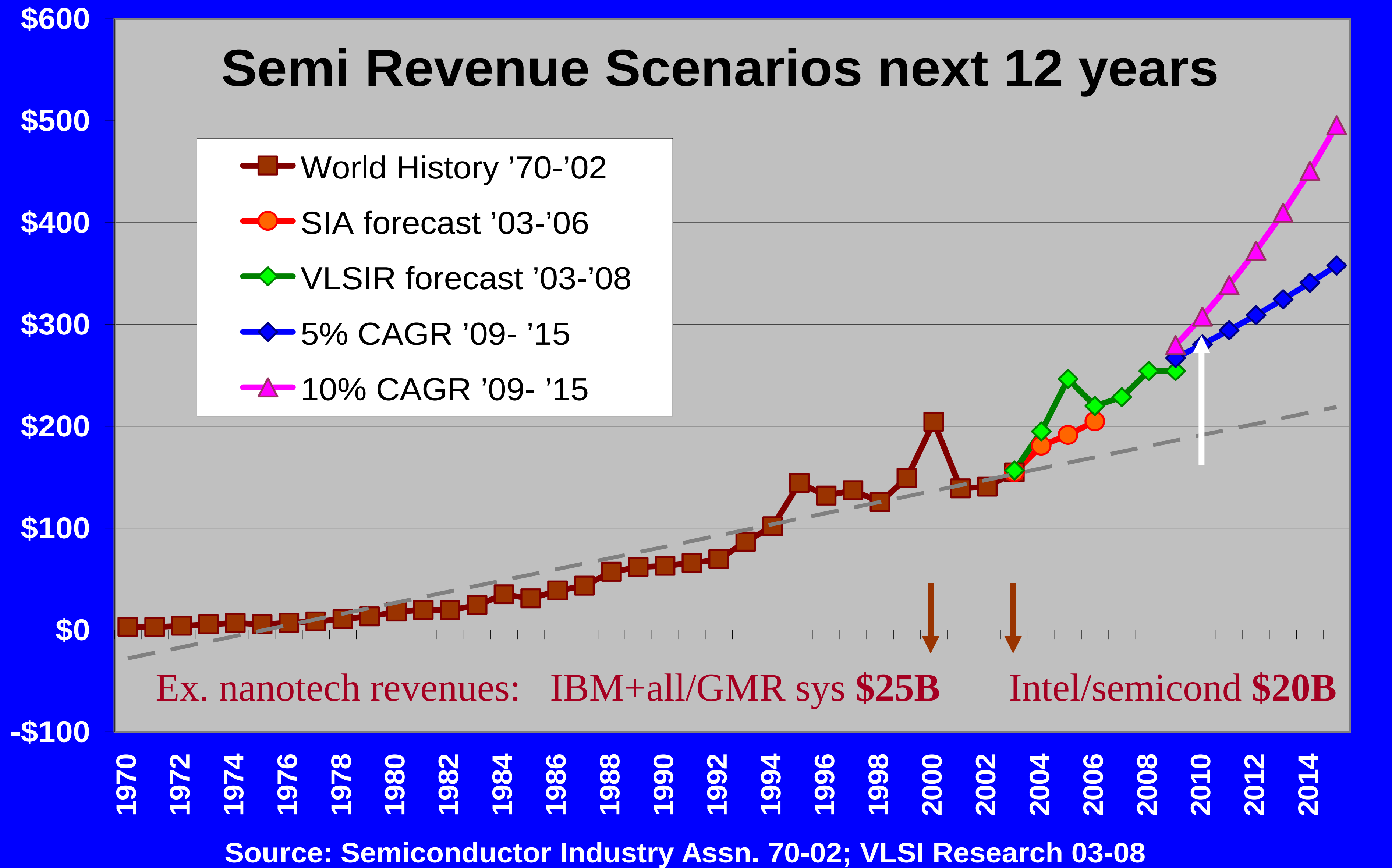
  Materials beyond chemistry: $340B/y
  Pharmaceuticals: $180 B/y
  Aerospace about $70B/y
  Electronics: over $300B/y
  Chemicals (catalysts): $100B/y
  Tools ~ $22 B/y

  Est. in 2000 (NSF) : about $40B for catalysts, GMR, materials, etc.; + 25%/yr
  Est. in 2002 (DB) : about $116B for materials, pharmaceuticals and chemicals

  Would require worldwide ~ 2 million nanotech workers

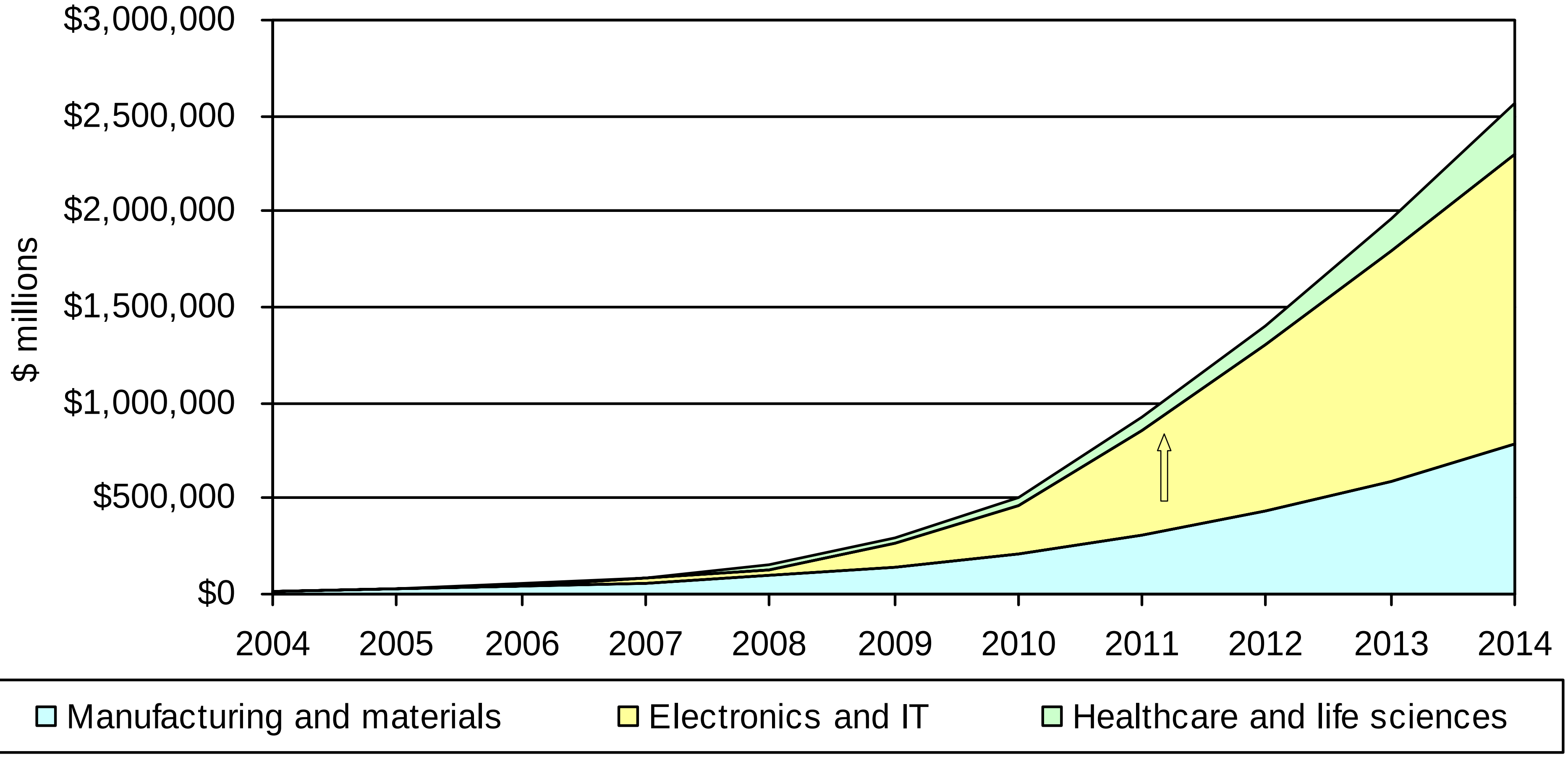
- **Improved healthcare**: extend life-span, its quality, physical capabilities
- **Sustainability**: agriculture, food, water, energy, materials, environment; ex: lighting energy reduction ~ 10% or **$100B/y**

Semiconductors Extrapolated to 2015 ($B)



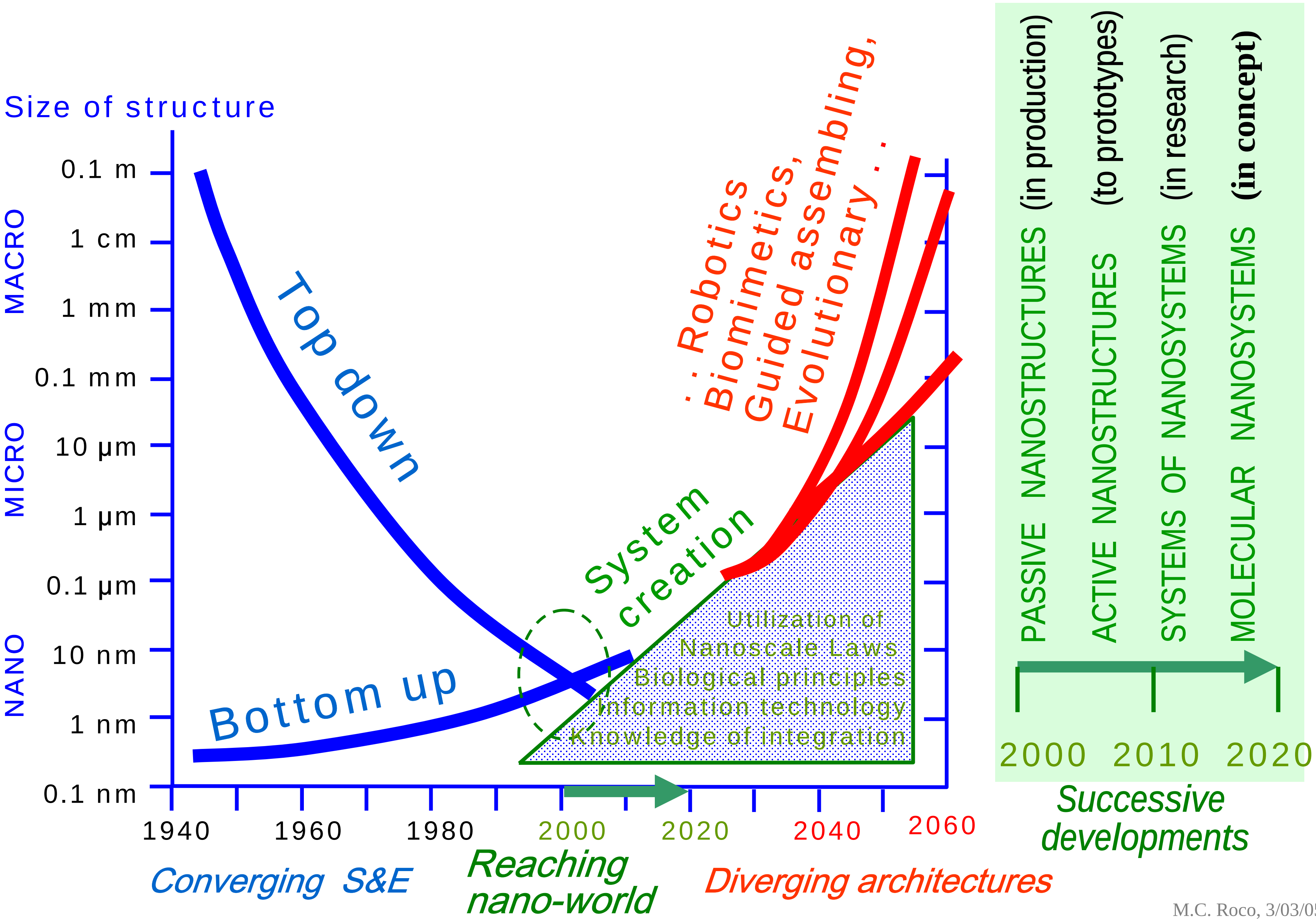
Note: $300B nanotech revenues sooner than predicted (2010 instead of 2015)

Global forecast, products sold incorporating emerging nanotechnology, 2004 to 2014, 3 sectors



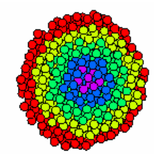
Source: October 2004 Lux Research Report “Sizing Nanotechnology’s Value Chain”

Reaching nano-world and system creation



M.C. Roco, 3/03/05

Timeline for beginning of industrial prototyping and nanotechnology commercialization: Four Generations

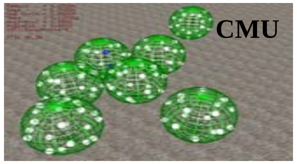


1st: Passive nanostructures (1st generation products)
Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

~ 2000

2nd: Active nanostructures Ex: 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures

~ 2005



3rd: Systems of nanosystems
Ex: guided assembling; 3D networking and new hierarchical architectures, robotics, evolutionary

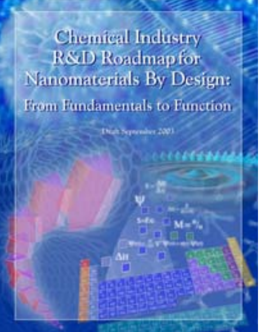
~ 2010

4th: Molecular nanosystems
Ex: molecular devices 'by design', atomic design, emerging functions

~ 2015-2020

R&D

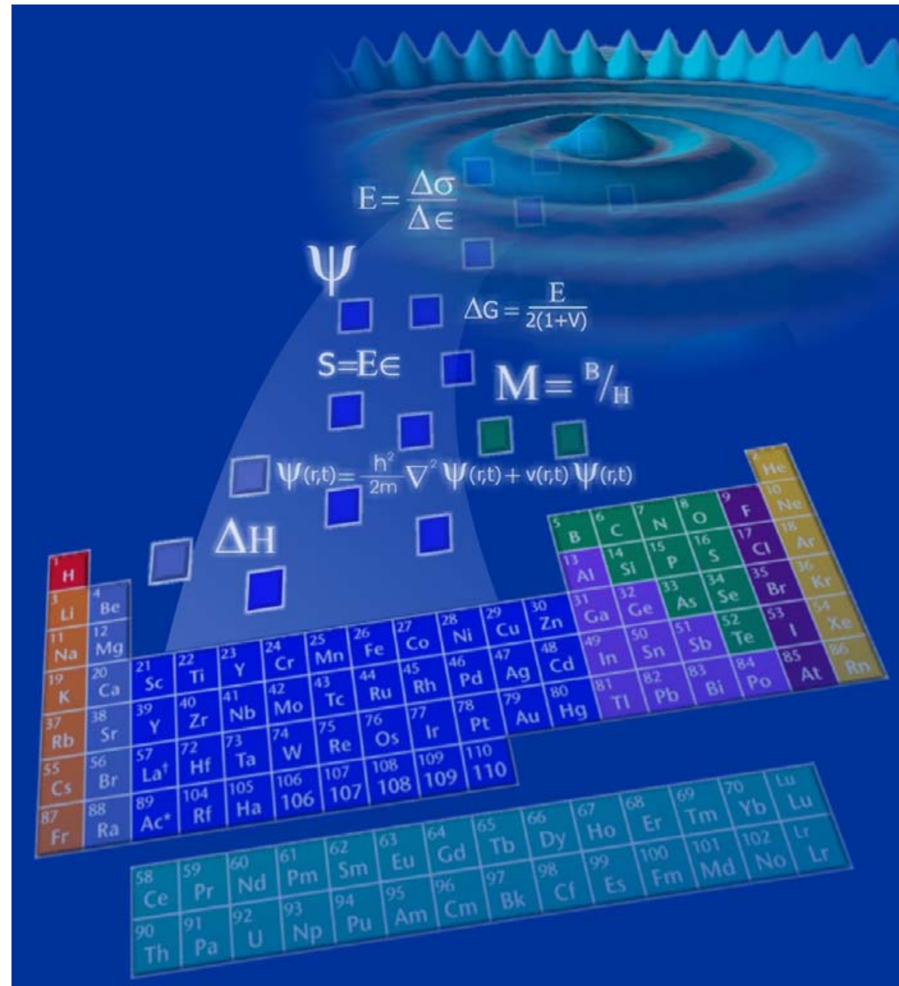
AIChE Journal, 2004, Vol. 50 (5), MC Roco



Nanomaterials By Design

www.ChemicalVision2020.org and NNI

The ability to employ scientific principles in deliberately creating structures with nano-scale features (e.g., size, architecture)
that deliver unique functionality and utility for target applications



Defining Nanomanufacturing

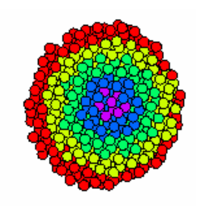
- Fragmentation,
- Patterning,
- Restructuring

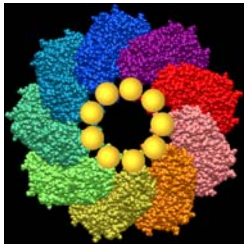
of bulk, ..

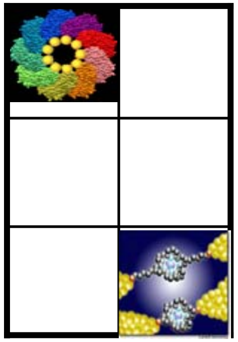
- Interfaces, field & boundary control,
- Positioning assembly
- Integration, ..

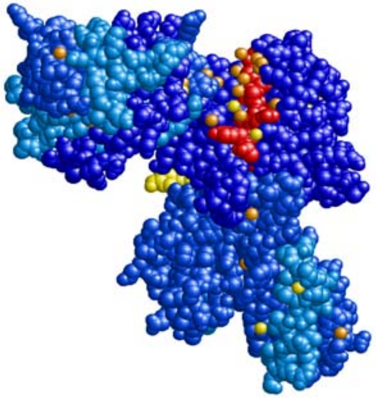
- System engineering,
- Device architecture,
- Integration, ..

- Nanosystem biology,
- Emerging systems, ..

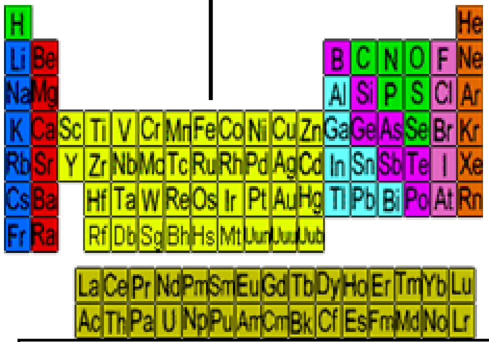








Assembling



- Directed selfassembling,
- Templating, ..

- Multiscale selfassembling,
- In situ processing, ..

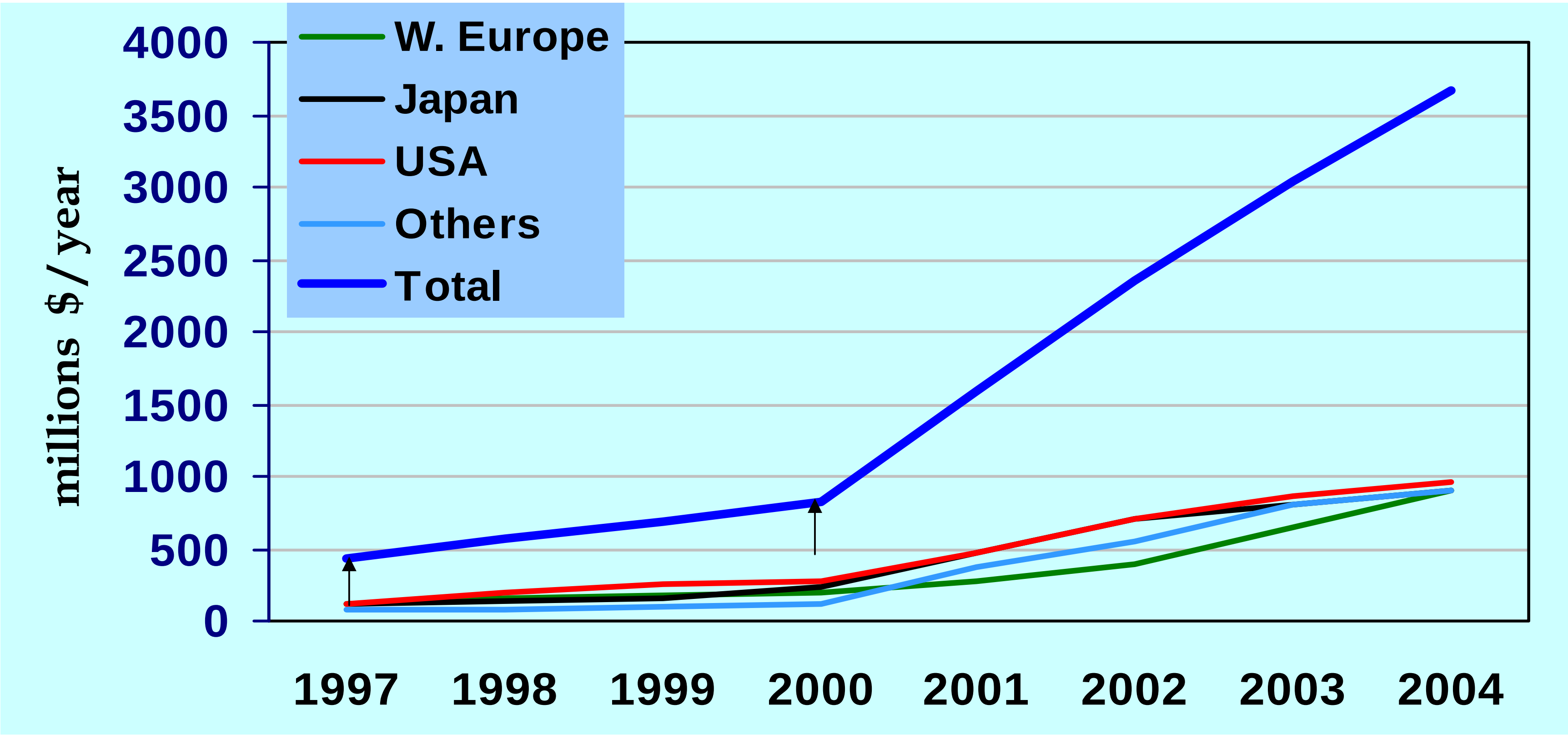
- Molecules as devices,
- Quantum control, ..

PASSIVE - ACTIVE - HETEROGENEOUS - MOLECULAR
NANOSTRUCTURES NANOSYSTEMS

MC Roco, NSF, 3/31/04

Context – Nanotechnology in the World

Past government investments 1997-2004 (est. NSF)

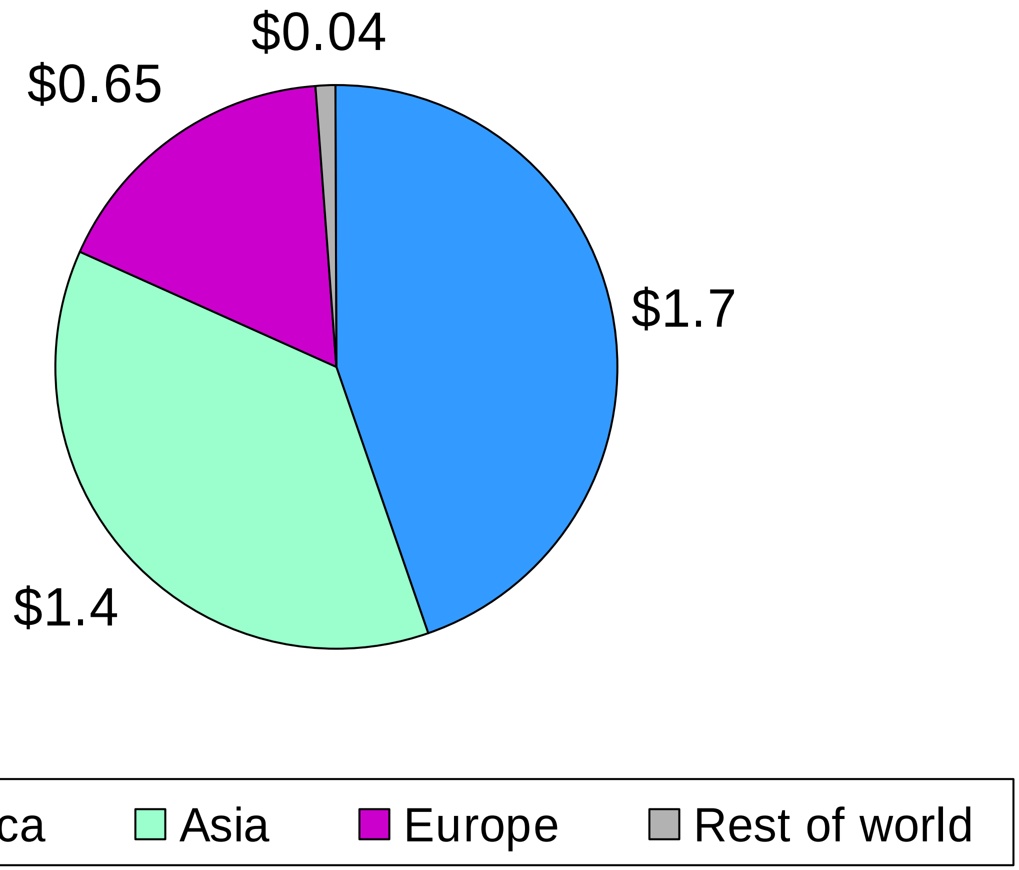


Note:

- **Total government expenditure in FY 2004 – about $3.7 billion**
- **U.S. begins FY in October, six months in advance of EU & Japan (in March/April)**

Established corporations will spend more than $3.8 billion globally on nanotechnology R&D in 2004

Corporate Nanotechnology Spending ($ billion)



Source: Lux Research reference study “The Nanotech Report 2004;” based on published spending figures, national statistics, Lux Research analysis

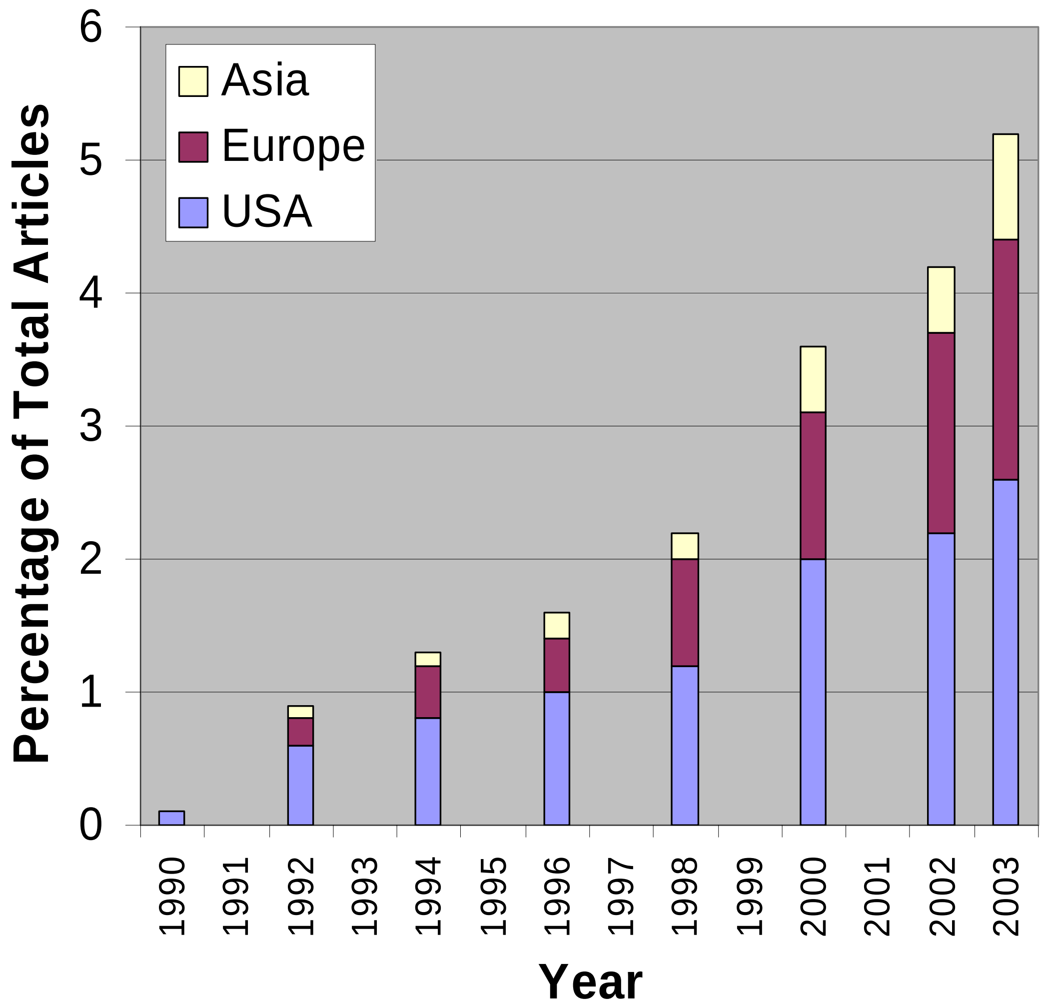
Exponential growth; About half of the highly cited papers in key journals originate in U.S.

("nano*" keyword search, after NNI Report, 2005)

Journal ISI with high Impact Factors (2001):

Nature	27.9
Science	23.3
Physics Review Letters	6.6

Correlates well with the overall papers with ISI high impact (UCLA study)

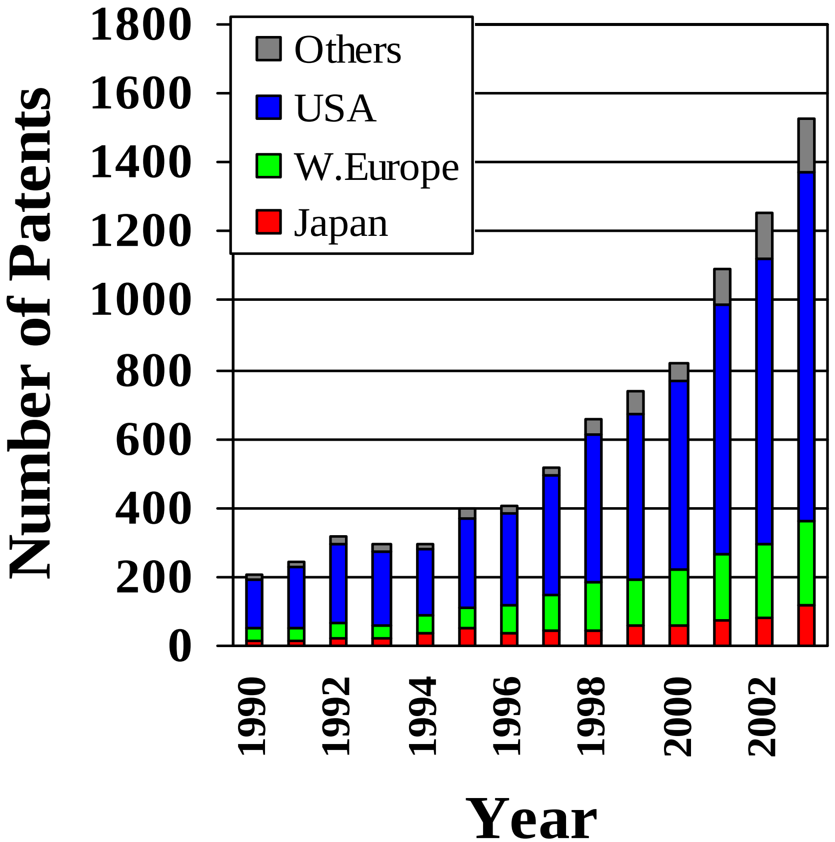


MC Roco, 3/03/05

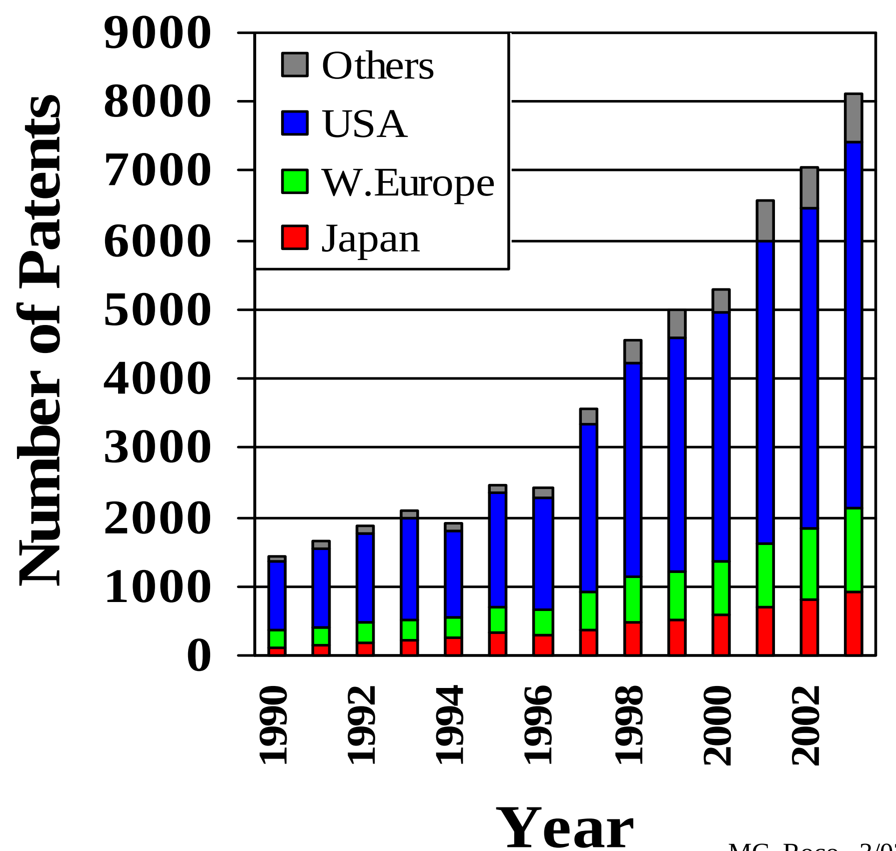
Exponential growth (USPTO database)

using “Title-claims”and “Full-text” search for nanotechnology by keywords
(using intelligent search engine, after J. Nanoparticle Research, 2004, Vol. 6 (4))

Using “Title-claims” search:
<u>nanotechnology claims</u>



Using “Full-text” search:
<u>nanotechnology claims,</u>
<u>or/and NSE tools and methods</u>



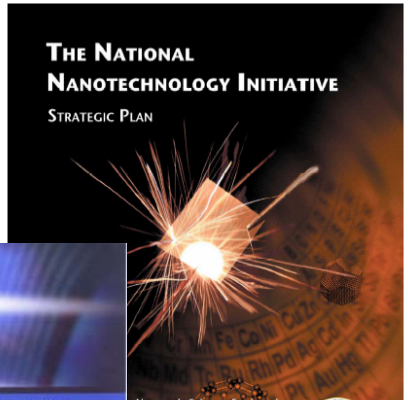
MC Roco, 3/03/05

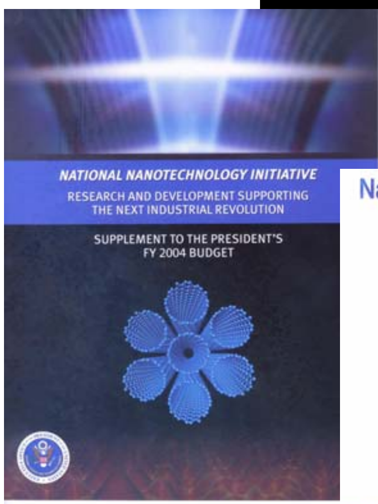
Defining the vision for the second strategic plan (II)

National Nanotechnology Initiative

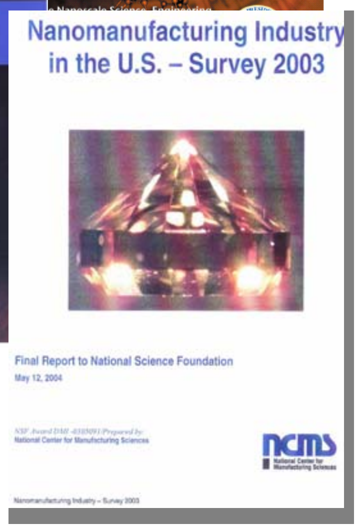
2004

2004: 10-year vision/plan



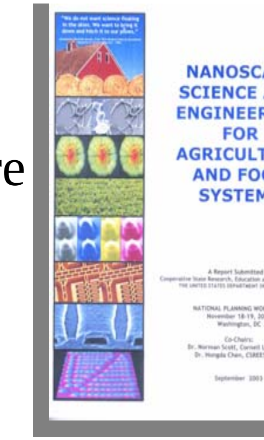


Government Plan (annual)

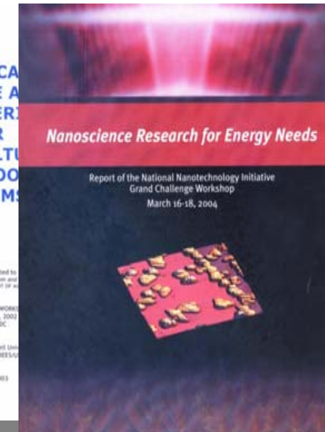


Survey manufacturing

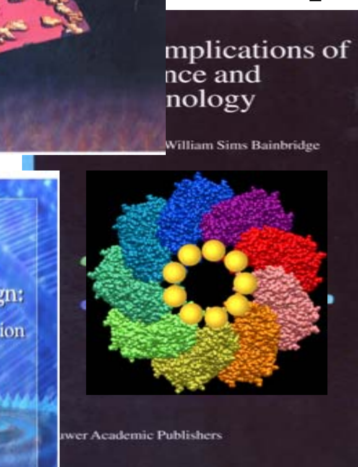
Agriculture and Food



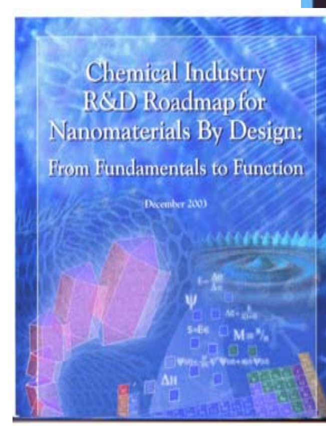
Energy



Societal Implications 2004

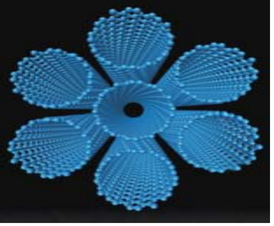


Reports



Other topical reports on www.nano.gov

2004: <u>Update 10 year vision, and develop strategic plan</u>

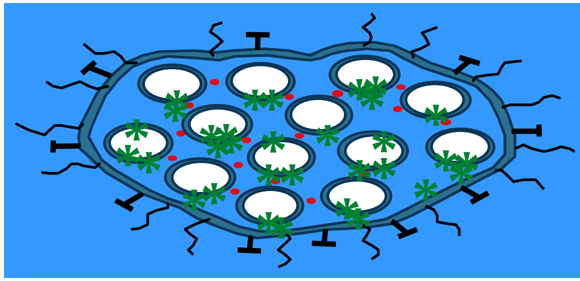


Second NNI strategic plan (2006-2010): Goals / Activities

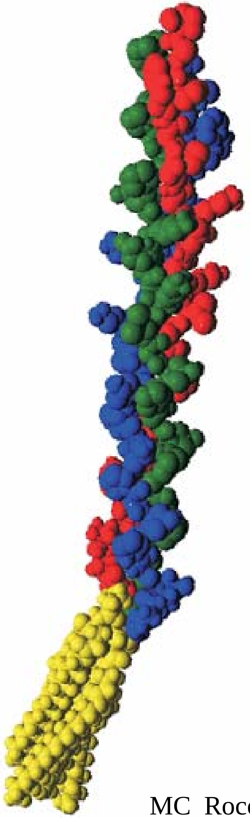
Four main goals *(including areas of new focus for next 5 years)*

- **Maintain a world-class research and development program** aimed at realizing the full potential of nanotechnology *(Support R&D for active nanostructures and nanosystems)*
- **Facilitate transfer of the new technologies** into products for commercial and public benefit *(Increase funding for technological innovation and multidisciplinary R&D platforms)*
- **Develop educational resources, a skilled workforce, and the supporting infrastructure** and tools needed to advance nanotechnology *(Access to research facilities and educational opportunities in nanoscale science and engineering for half of the undergraduate and graduate students by 2010)*
- **Support responsible development of nanotechnology** thru societal, environmental and health implications R&D, and interaction with the public *(Address sustainability and life cycle of products)*

Example:
Synthesis and control of nanomachines
(examples NSE in 2004, www.nseresearch.org - 300 projects)

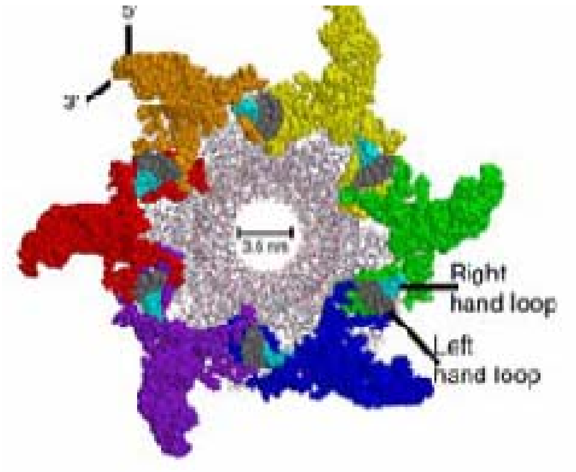


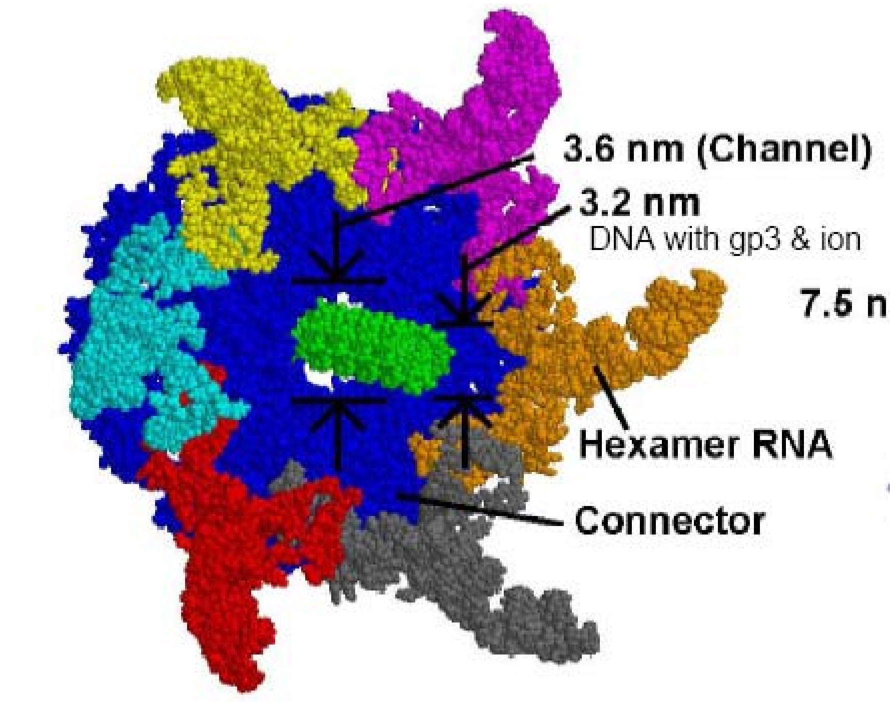
- **Self-assembly processing** of nanoscale bio-materials and devices for micromachines components (UCSB)
- Chemistry to synthesize components of **nano machines to work on surfaces** and be activated by external electromagnetic fields (UCB)
- **Light driven molecular motors** (U. Nevada)
- **Combinatorial engineering of nanomachines**, with application to membranes and filters (U. Penn.)
- **Nanoengineering surfaces** for probing viral adhesion (UC Davis)

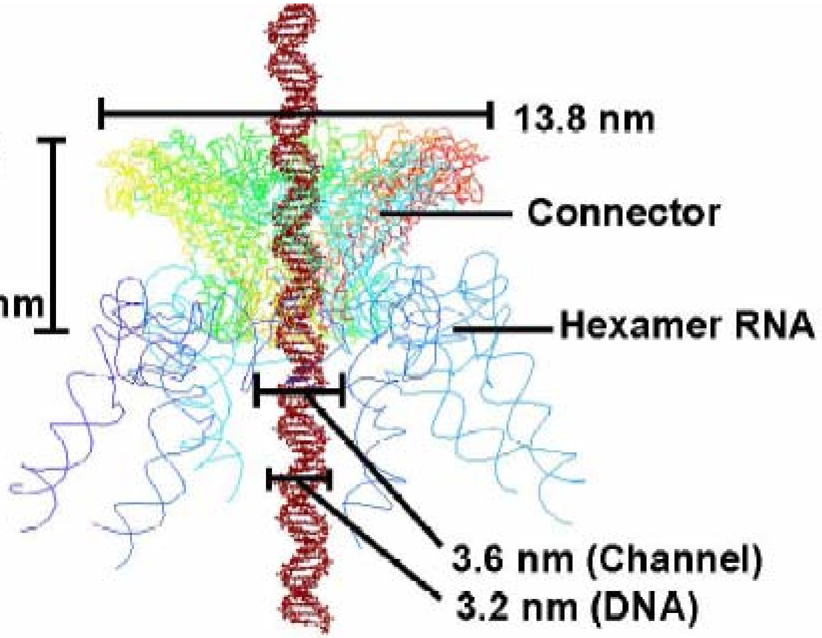


Example:
Construction of a Viral Nanomotor Driven by a Synthetic RNA

P. Guo, Molecular Virology,
Purdue University, 2004

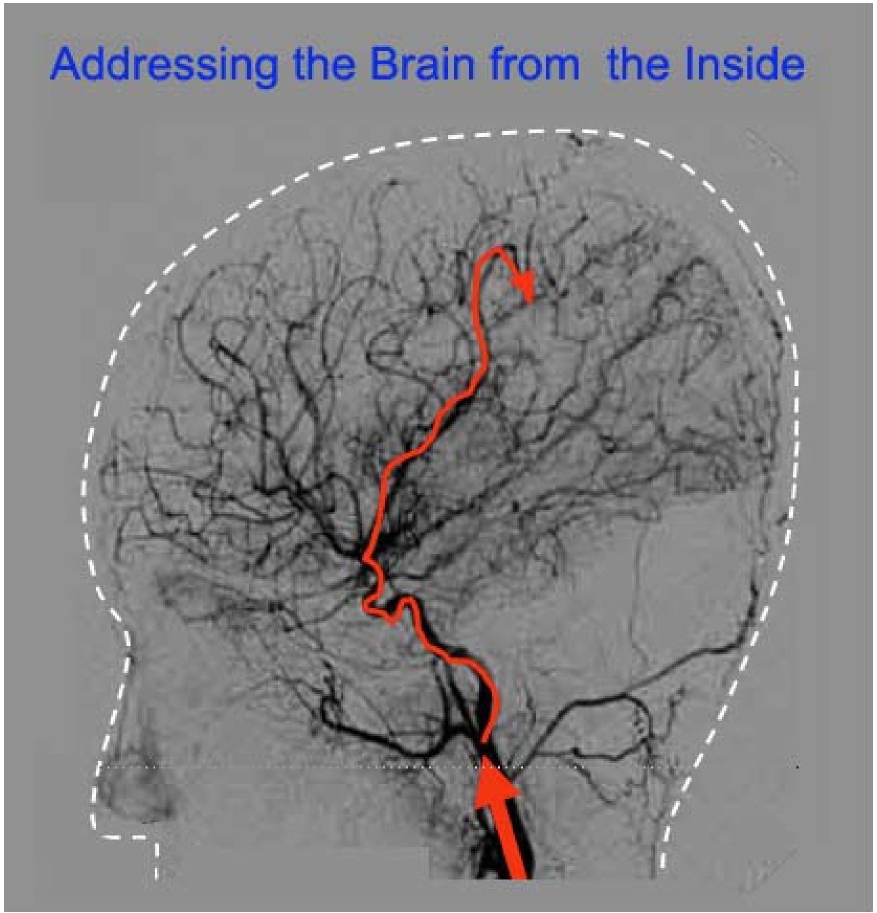






Example: Neuro-vascular Central Nervous Recording/ Stimulating System: Using Nanotechnology Probes

R.R. Llinás, NYU School of Medicine
I. Hunter, MIT, Bioengineering



Nanostructured polymeric wires, biocompatible, biodegradable and with guidance

Several goals:

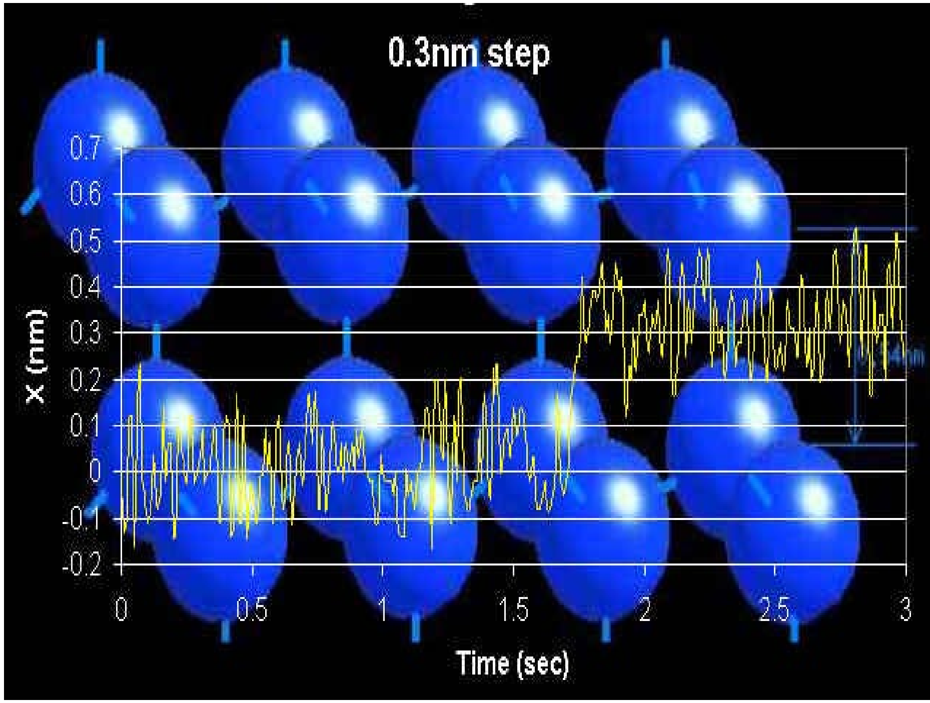
- neuro-to-neuron interaction
- simultaneous multiple probes for describing the system
- treatment Parkinson disease

Example:

Subnanometer resolution on a large domain

Specifications

- 0.1 nanometer resolution (or better)
- 10.0 nanometer accuracy
- 1 mm/sec maximum velocity
- NSOM, AFM or optical microscope probe
- Short term testing with confocal like microscope



Domain

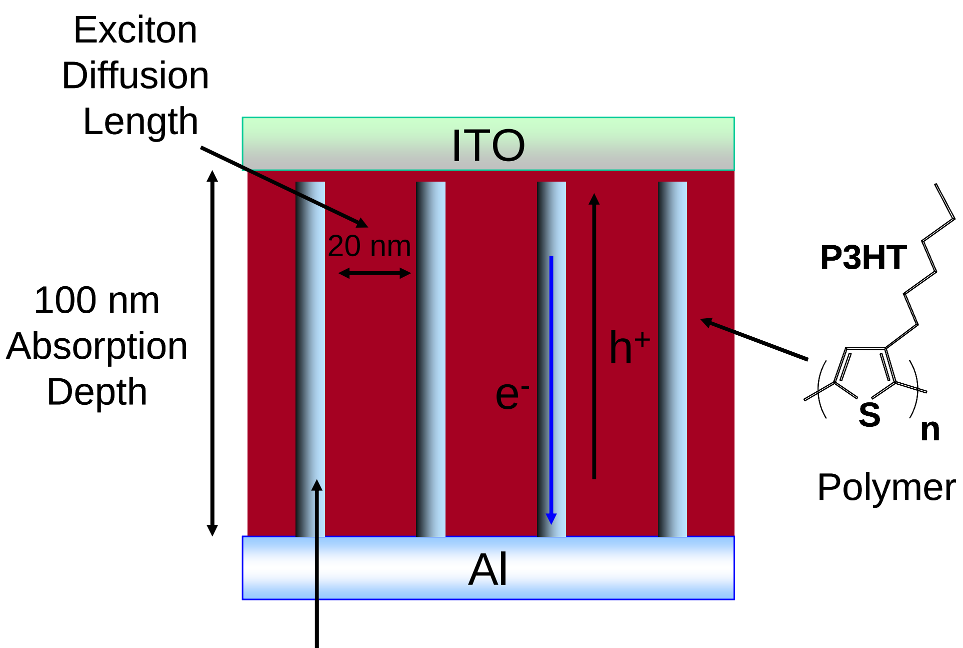
•25 mm x 25 mm lateral travel

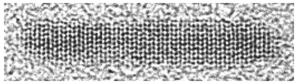
•100 micrometers vertical travel

Eight - pass interferometer

NCSU, R. Hocken

Energy: Schematic design of the nanorod-polymer solar cell





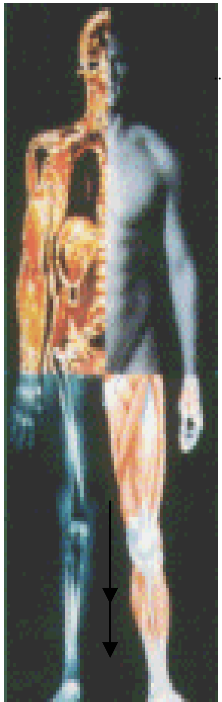
transmission electron micrograph
of a CdSe nanorod at the bottom

(courtesy P. Alivisatos, Univ. California, Berkeley; and Nanosys, Inc.).

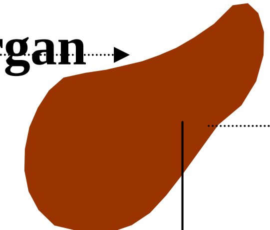
Examples of levels for intervention of nanobiotechnology

in human life extension

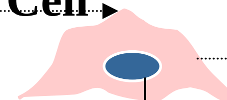
Human



Organ



Cell



Molecule

- Joint replacement
- Non-invasive and invasive diagnostics for rapid patient monitoring
- Cognitive-assist devices
- Targeted cancer therapies

- Artificial organs
- Sensors for in vivo monitoring
- Localized drug delivery
- Neural stimulation
- Cardiac therapies

- Improved cell-material interactions
- Scaffolds for tissue eng.
- Genetic therapies
- Cell ageing
- Stem cell therapies

- Localized drug delivery
- Gene therapy devices
- Self-assembly structures
- Fast diagnostic techniques

(NBIC Report, 2002)

After 3 years of NNI:
New R&D potential targets for 2015 (ex.)

2004 **2015**

Nanoscale visualization and simulation of 3D/m domains

= Micro domains with nano space and time resolutions

Transistor beyond/integrated CMOS under 10 nm

New catalysts for chemical manufacturing

No suffering and death from cancer when treated

Control of nanoparticles in air, soils and waters

After 3 years of NNI:

New R&D potential targets for 2015 (2)

2004 **2015**

Advanced materials and manu.: ½ from molecular level

Pharmaceuticals synthesis and delivery: ½ based on nano

Converging technologies from the nanoscale

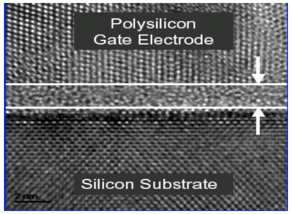
Including: artificial organs, manufacturing multidisciplinary platforms, etc.

Life-cycle biocompatible/sustainable development

Education: nanoscale instead of microscale-based

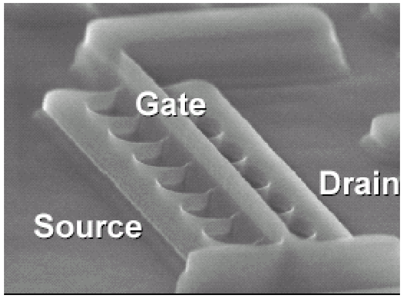
Challenge 2015: Transistor beyond/integrated CMOS under 10 nm

- In the 70s, 80s and 90s
  Geometrical scaling was the major driver
- In the 2003 - 2012 period (industry target)
  Use of novel physical phenomena to extend performance by equivalent scaling are the major drivers. Examples (2004):



1.2 nm gate oxide is ~5 Silicon atom layers thick

"Strained Silicon" - Separating the Silicon Atoms for Faster Electron Flow



Tri-gate Transistor

In addition, to explore beyond CMOS:
- New carriers instead of electron charge
- Integrate CMOS with other nanodevices
- New system architectures
- Integration with applications

Challenge 2015: To simulate engineering problems from basic principles at the nanoscale

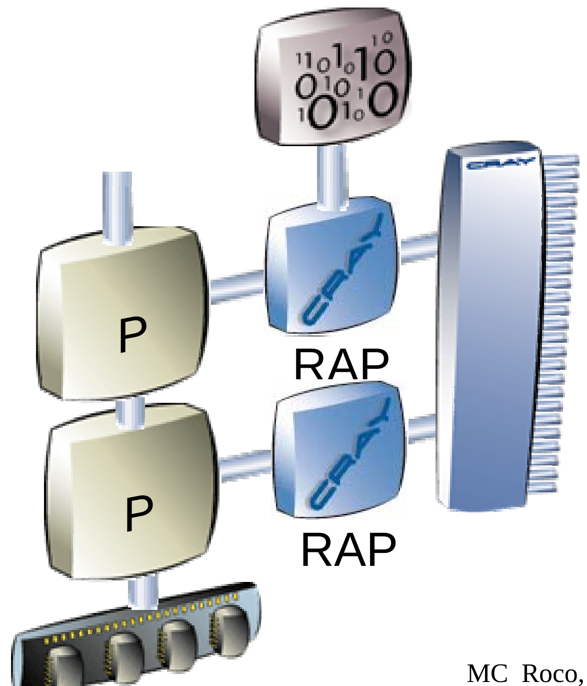
Using nanotechnology to build the highest speed processors

Using fast computers and reconfigurable computing for nanoscale S&E "application acceleration"
(for 100x potential speeedup)

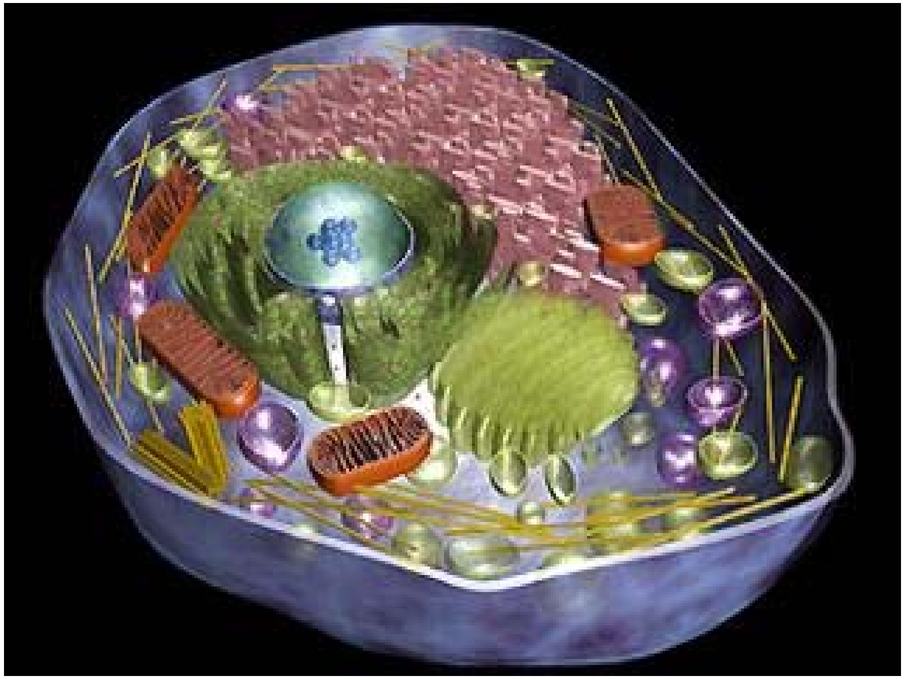
Capability 2004 (Cray X1):
50+ TFLOPS (fastest computer in the world)

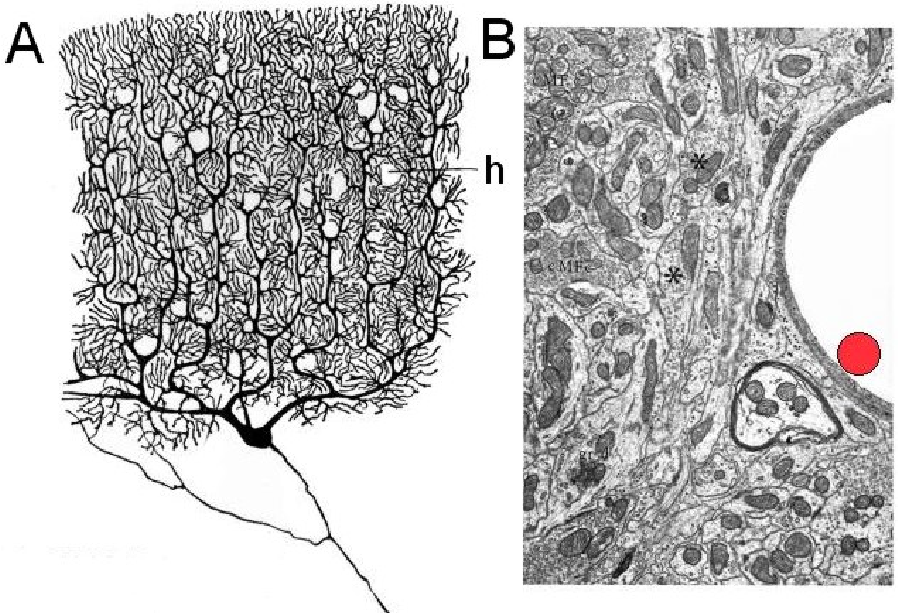
~ 2010 (Cray Cascade):
DARPA – NSF – DOE acad. support
1,000+ TFLOPS

~ 2015 (Cray target):
10-100,000 TFLOPS



Challenge 2015: Specify the state of a cell and of nervous system from the nanoscale





R. Llinas, 2003

The Cell

– basic nanosystem of life

The brain

– complex system based on nanoscale processes

Measure and simulate, 3 dimensional, highly parallel, . . .

Challenge 2015: To Eliminate Suffering and Death Due to Cancer

"A Vision Not a Dream!" by using nanotechnology, A v. *Eschenbach, NCI*

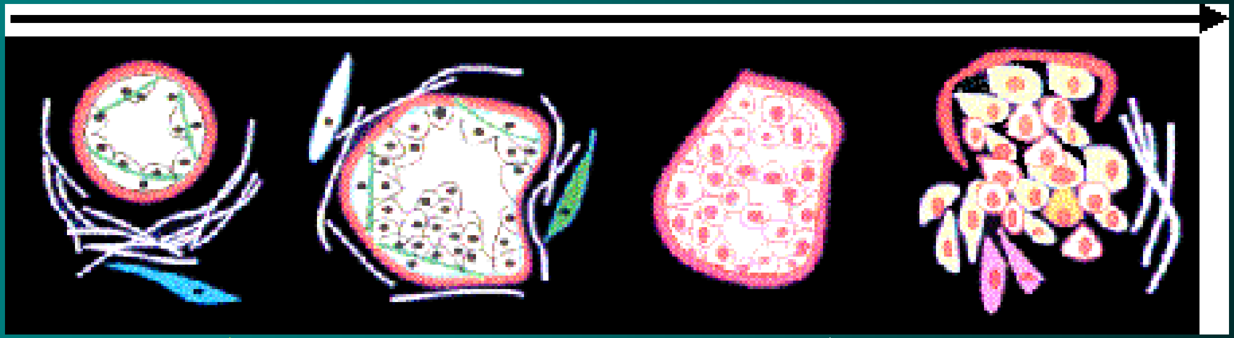
Where We Want To Be ← Where We Are

Detection and Diagnosis

Detection and Diagnosis

Malignant Tumors With Metastases

Year 0 Year X Year Y Year Z



Prevention

Prevention

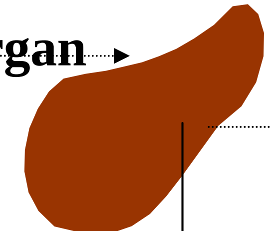
Cancer results from accumulation of multiple genetic changes in a cells.
Nanotechnology will allow earlier detection and prevention (Year 0)

Examples of levels for intervention of nanobiotechnology

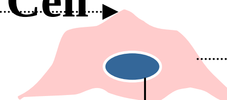
in human life extension

Human

Organ



Cell



Molecule

- Artificial organs
- Sensors for in vivo monitoring
- Localized drug delivery
- Neural stimulation
- Cardiac therapies

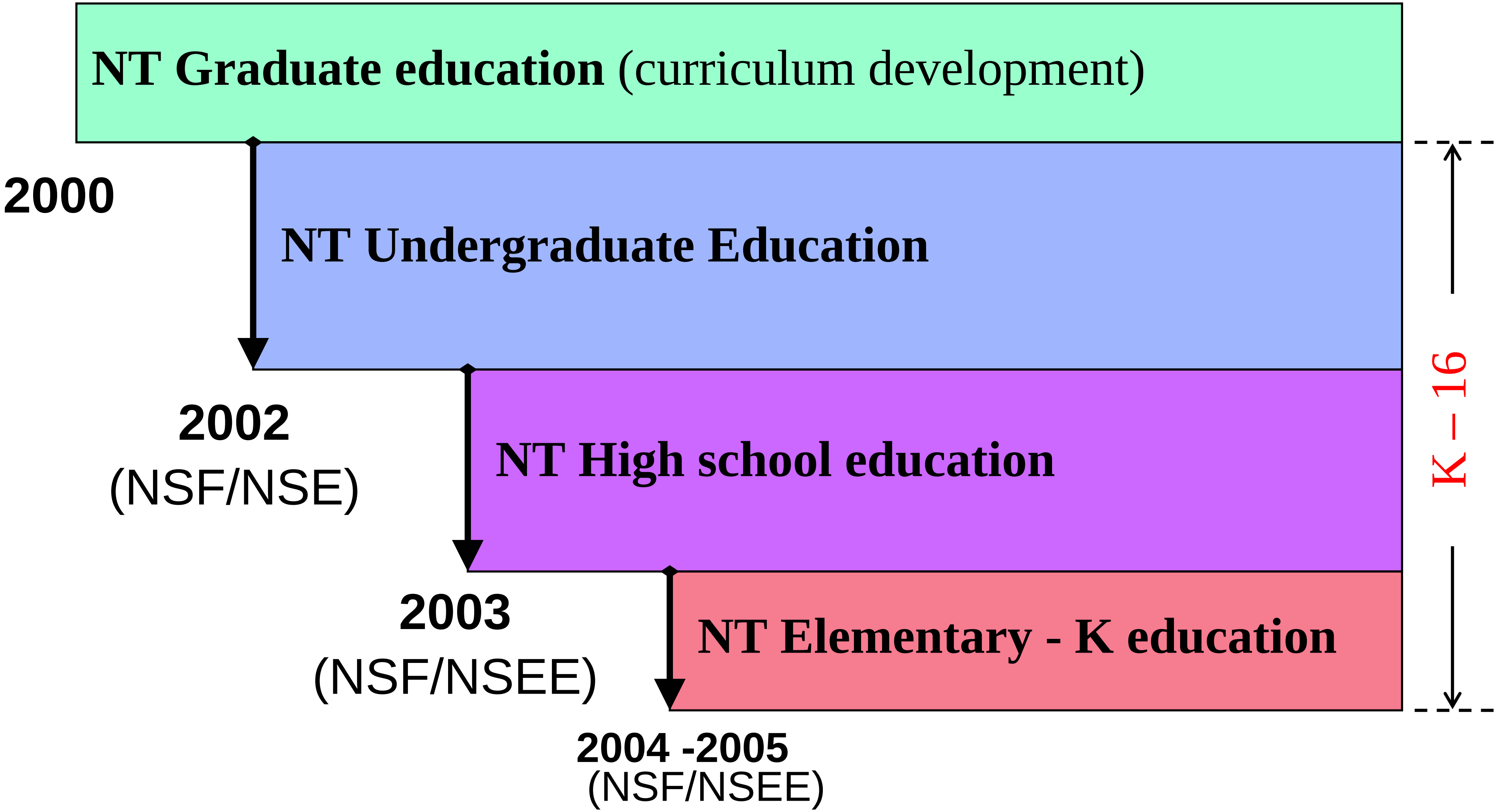
- Improved cell-material interactions
- Scaffolds for tissue eng.
- Genetic therapies
- Cell ageing
- Stem cell therapies

- Localized drug delivery
- Gene therapy devices
- Self-assembly structures
- Fast diagnostic techniques

- Joint replacement
- Non-invasive and invasive diagnostics for rapid patient monitoring
- Cognitive-assist devices
- Targeted cancer therapies

(NBIC Report, 2002)

Introducing earlier nanotechnology education
(NSF: Nanoscale Science and Engineering Education)



Objectives for nanotechnology education

- Fundamental understanding from the nanoscale:
  moving the foundation of learning from "microscale" to "nanoscale"
- Sharing similar concepts in various disciplines and relevance areas:
  unifying concepts earlier in education
- **"Reversing the pyramid of learning"**: learning first unifying concepts of matter/ biology/ information systems, and then averaging techniques specific to each discipline
- **Combine "depth" with "breadth"**
- **Broader accessibility and motivation to S&T**
- **Engineering has an increased role** because of its interdisciplinary, integrative, system approach and transforming characteristics. Nanotechnology deals with systems.

(*M. Roco, Nature Biotechnology, 2993, Vol. 21, 1247-1250)*

Nanotechnology education: What to do in the future?

- **Developing coherent, longitudinal program** with proper bridges between K-12, UG, G, postdoctoral, and continuing education, and encouraging earlier nanotechnology education
- **Targeting systemic changes K-16**
- Priority to unifying S&E and broad relevance courses
- Partnering for cross-disciplinarity, cross-relevance, and sharing resources (such as facilities and expertise, remote)
- Enabling the teachers
  - Training activities periodical available (ex: RET, at centers)
  - Create educational materials (modules, hand-on-kits, course notes)
  - Access to experimental facilities and specialized museums
- International education opportunities Young researchers to Japan and EU; PASI - Latin America, NSF-E.C.

Infrastructure 2001-2004: 33 R&D Centers, Networks and User Facilities

Funded by NSF (21), DOD (3), NASA (4), and DOE (5)

2000

Nanobiotechnology, Cornell (STC)

Network for Computational Nanotechnology (7)

Oklahoma Nano Net

2001

Nanoscale Systems in Information Technologies (NSEC)
Nanoscience in Biological and Env. Eng. (NSEC)
Integrated Nanopatterning and Detection (NSEC)
Electronic Transport in Molecular Nanostructures (NSEC)
Nanoscale Systems and their Device Applications (NSEC)
Directed Assembly of Nanostructures (NSEC)

Institute for Soldier Nanotechnology (UARC)
Nanoscience Innovation for Defense, MIT
Nanoscience Institut, NRL

2002

MRSECs on nanostructures

Institute for Cell Mimetic Space Exploration
Institute for Intelligent Bio-Nanomaterials & Structures for Aerospace Vehicles
Bio-Inspection, Design, and Processing of Multi-functional Nanocomposites
Institute for Nanoelectronics and Computing

2003

Integrated and Scalable Nanomanufacturing (NSEC)
Nanoscale Chem., Electr., and Mech. Manu. Systems (NSEC)
Extreme Ultraviolet Science and Technology (ERC)

National Nanotechnology Infrastructure Network (13)

2004

Integrated Nanomechanical Systems (NSEC)
High Rate Nanomanufacturing (NSEC)
Affordable Nanoeng. of Polymer Biomedical Devices (NSEC)
Nano/Bio Interface (NSEC)
Probing the Nanoscale (NSEC)
Templated Synthesis and Assembly at the Nanoscale (NSEC)

Operation 2005-2007

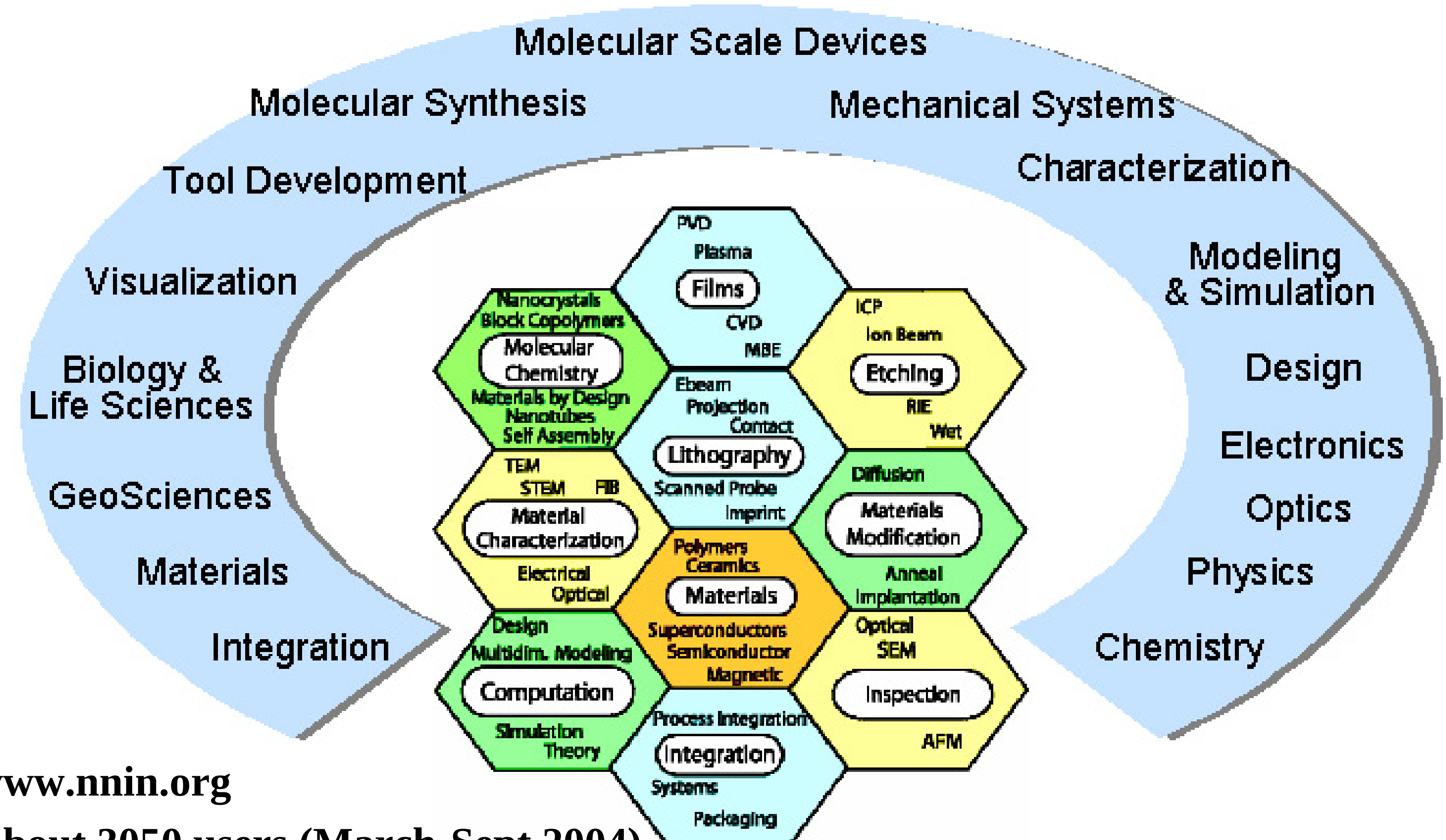
Molecular Foundry
Center for Integrated Nanotechnologies
Center for Nanophase Materials Sciences
Center for Nanoscale Materials
Center for Functional Nanomaterials

2005

Nanotechnology Center for Learning and Teaching (10)

MC Roco, 3/03/05

NSF NNIN Scope and Activities
(13 nodes, lead Cornell University)

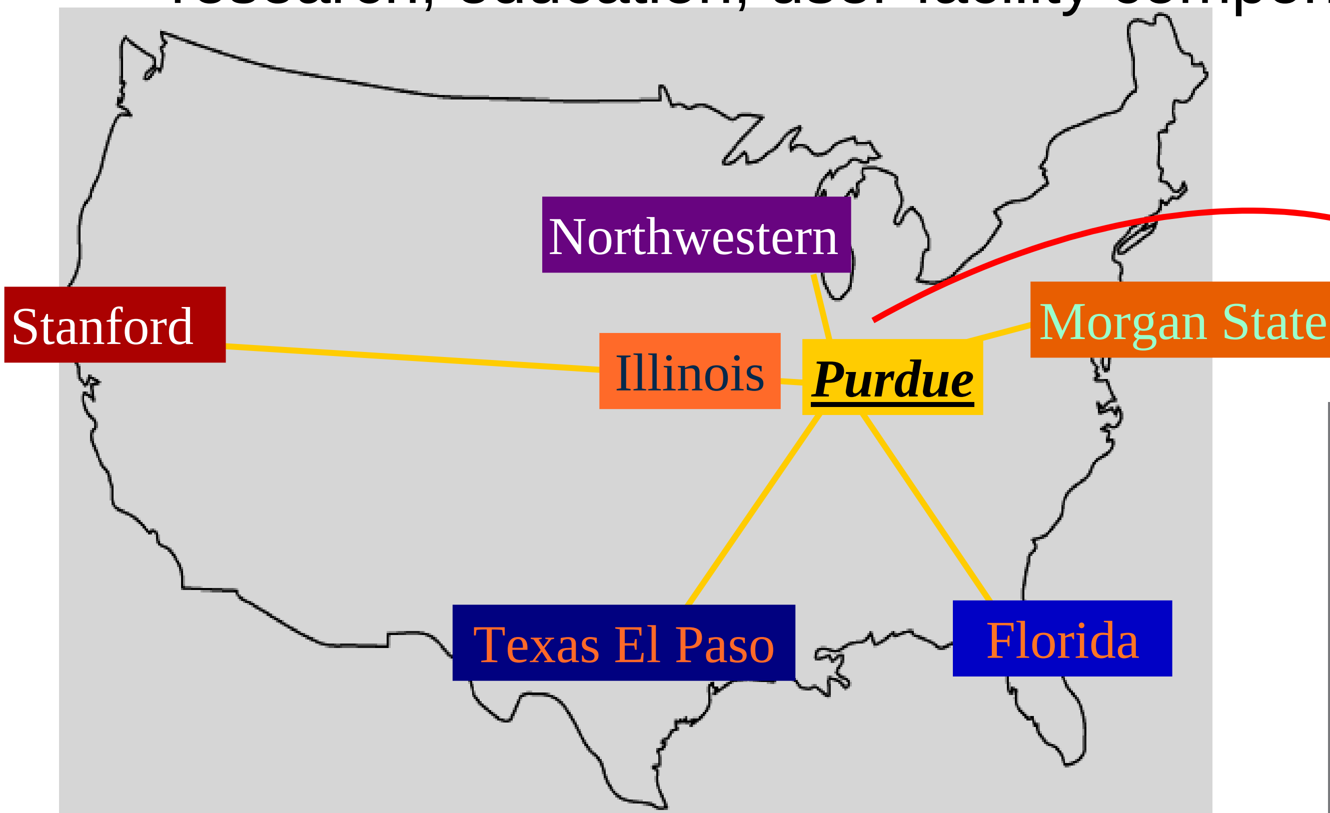


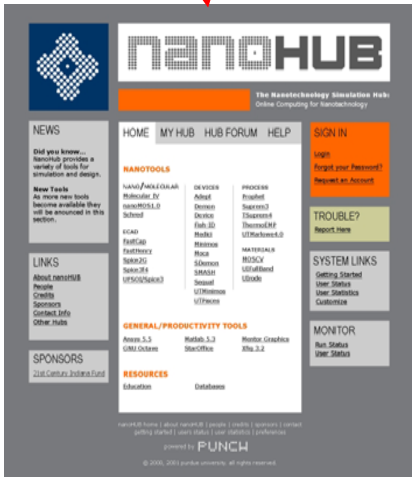
www.nnin.org

About 3050 users (March-Sept 2004)

Network for Computational Nanotechnology (7 nodes, lead Purdue University)

Multi-scale, multi-disciplinary from "atoms to systems" research, education, user-facility components





www.nanohub.purdue.edu ; About 3,000 users in FY 2004

DOE Nanoscale Science Research Centers

Summer '03

Center For Nanophase Materials Sciences at ORNL

Spring '05

Center For Functional Nanomaterials at BNL

Spring '04

Molecular Foundry at LBNL

Spring '04

Center for Nanoscale Materials at Argonne

Center for Integrated Nanotechnologies

NNI-Industry Consultative Boards for Advancing Nanotech

Key for development of nanotechnology, Reciprocal gains

- **NNI-Electronic Industry (SRC lead), October 2003**
  - Collaborative activities in key R&D areas
  - 5 working groups, Periodical joint actions and reports
  - NSF-SRC agreement for joint funding; other joint funding
- **NNI-Chemical Industry (CCR lead)**
  - **Joint road map for nanomaterials R&D**
  - **2 working groups, including on EHS**
  - **Use of NNI R&D results, and identify R&D opportunities**
- **NNI – Organizations and business (IRI lead)**
  - **Joint activities in R&D technology management**
  - **2 working groups (nanotech in industry, EHS)**
  - **Exchange information, use NNI results, support new topics**
- **In developments: NNI - Pharmaceuticals (Phrma lead)**
  NNI - Automotive industry

Precompetitive Nanotechnology Platforms

- Synergistic development by using **same nanotechnology principles and transforming tools** for various applications
- **Integrate nanoscale knowledge with biotechnology**, **information technology and cognitive sciences** for new tools and treatment concepts
- Accelerate nanotechnology applications using a **“system approach”**
- Establish **multidisciplinary clusters**
- Develop **new mechanisms for information, communication and collaboration** between researchers, industry/hospitals and public

GE Nanotechnology Platform

Aircraft Engines

Water

NanoTubes and NanoRods

NanoParticles

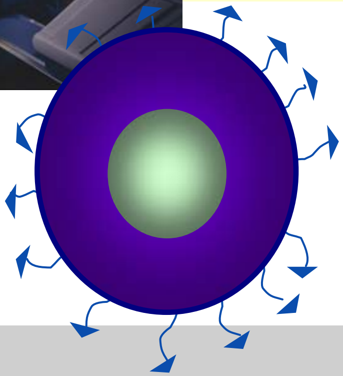
NanoCeramics

NanoStructured Metal Systems

Hybrid Materials

Energy

Healthcare



Industry surveys

- Companies working in nanotechnology

Survey by Small Times in 2004, based on individual contacts and direct verification:

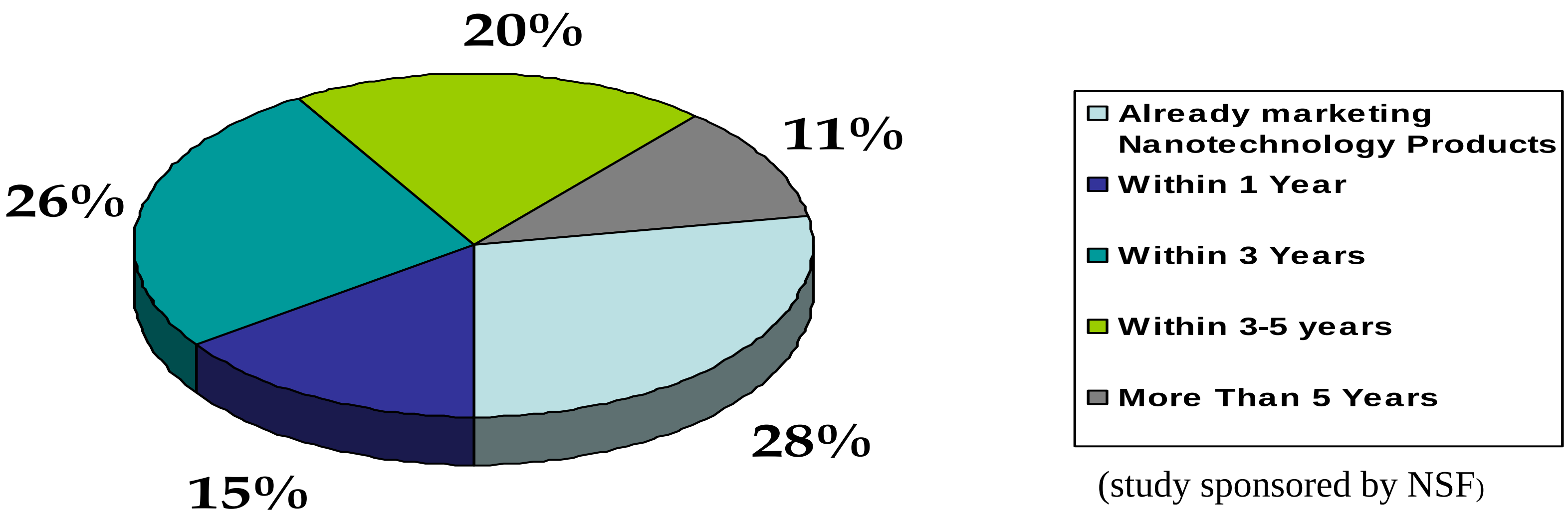
875 nanotech companies

475 products in 215 companies

- Timeline for commercialization

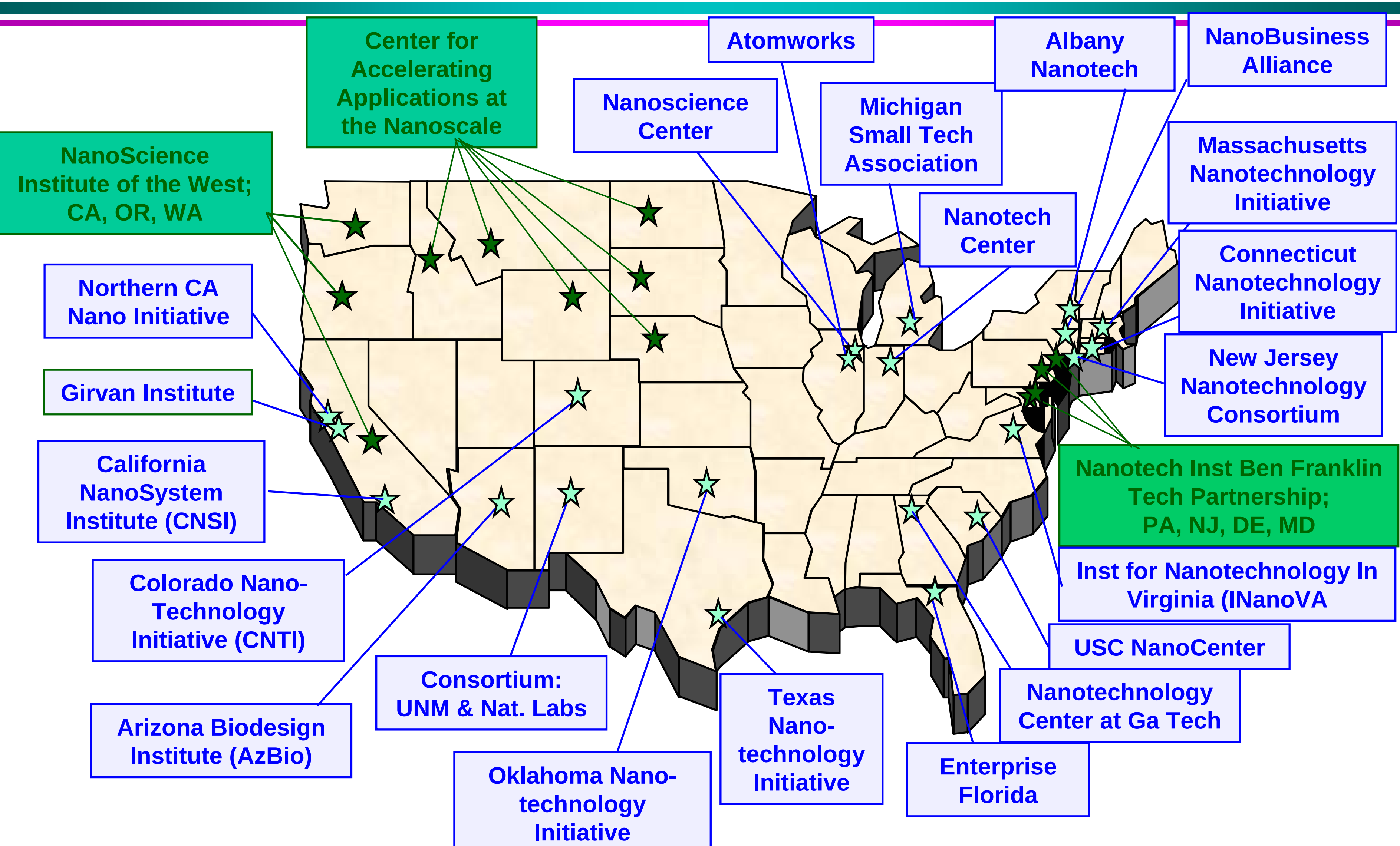
Survey by National Center for Manufacturing Sciences:
81 manufacturing companies:

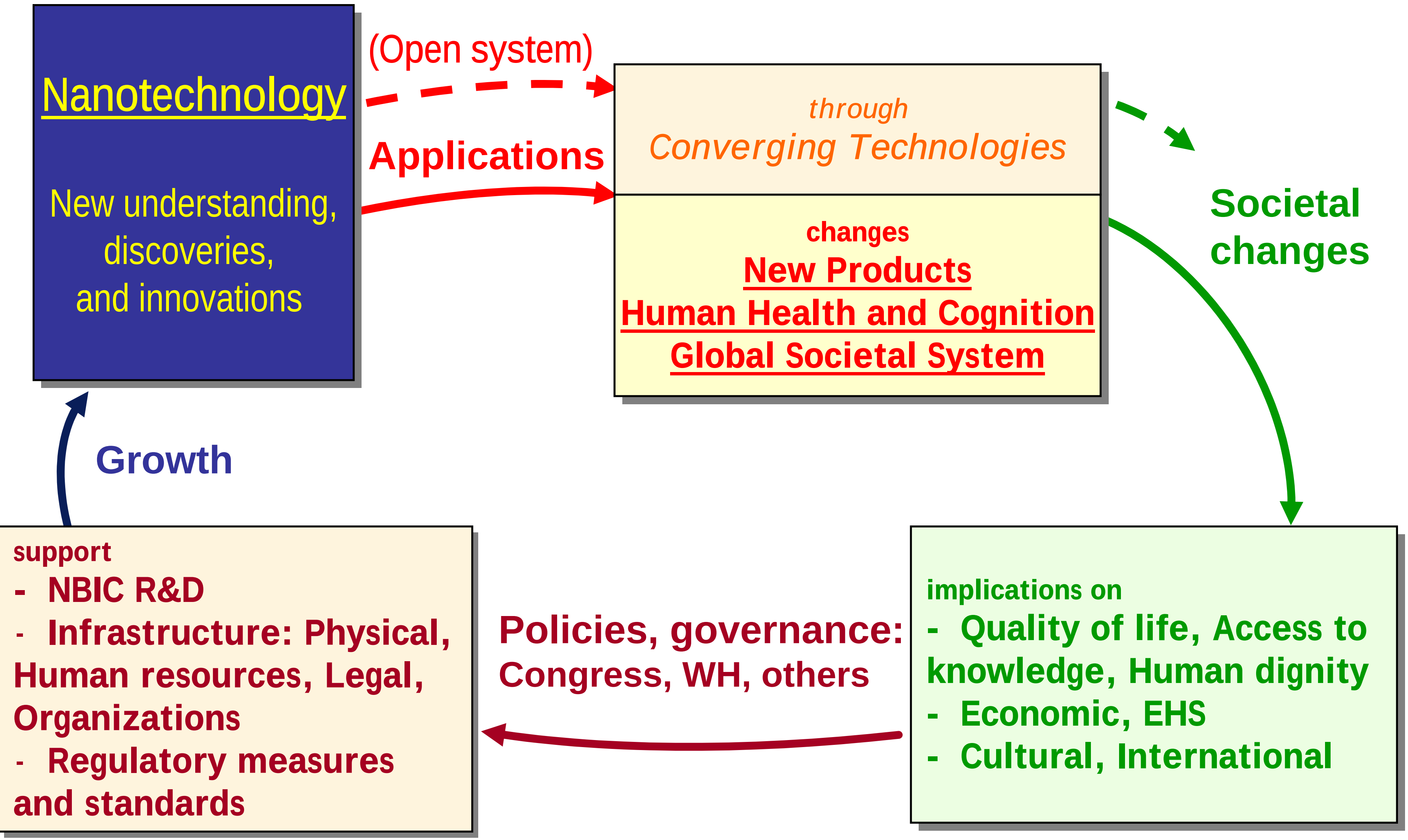
89% expect products in less than 5 years



(study sponsored by NSF)

Sampling of Current Regional, State, & Local Initiatives in Nanotechnology





Nanotechnology in Society

J. Nanoparticle Research, 7(2), 2005

M.C. Roco, 3/02/05

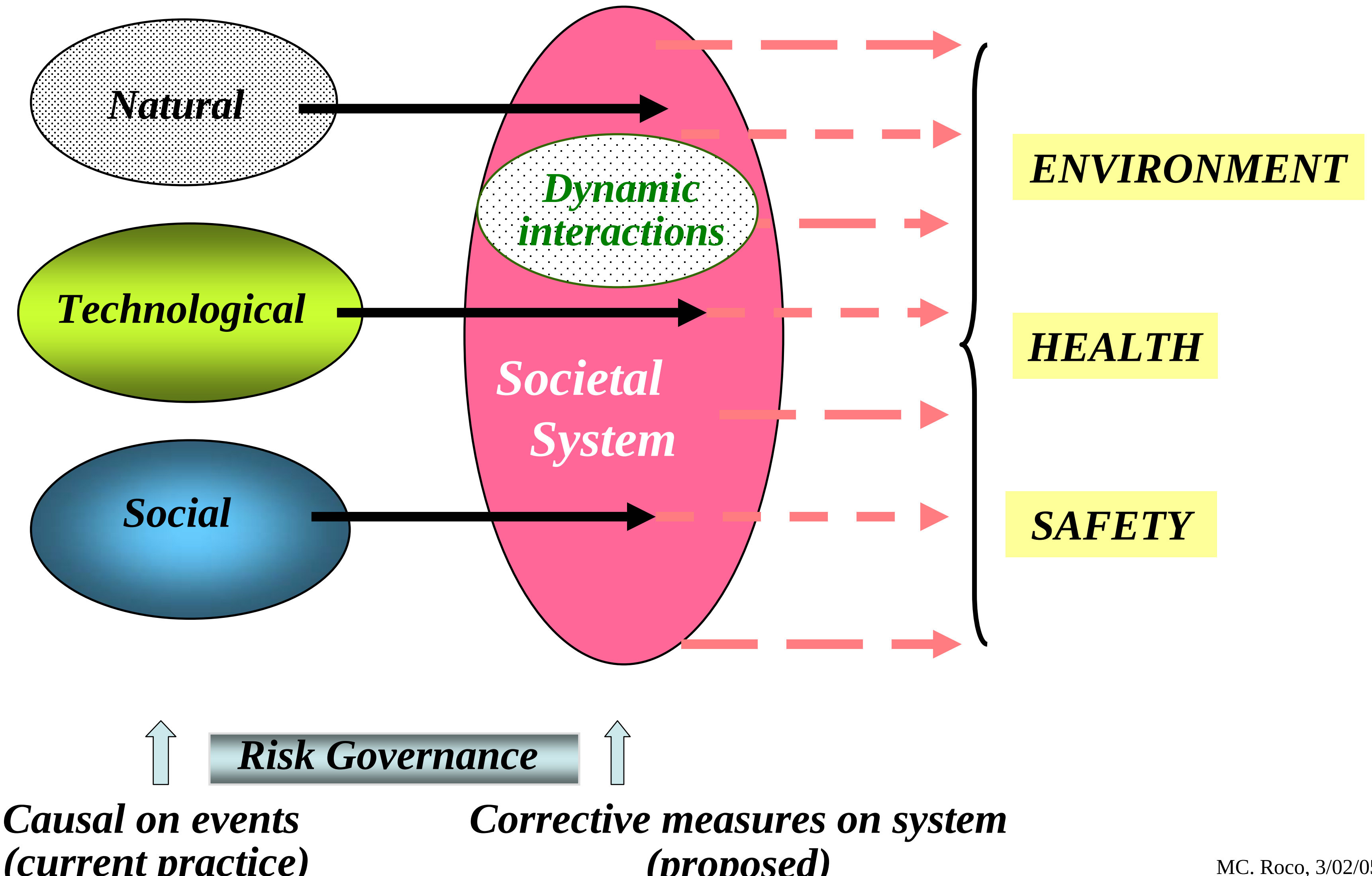
Specific framework for risk governance of nanotechnology

Focus on risk analysis for the higher-risk applications:

- an open and complex system
  - fundamental (high risk)
  - developments are not known (role organizations)
  - accelerated (upstream measures needed)
  - cross S,E&T (complex interactions)

- with broad implications (general platform)
  - affects most areas of economic activity, effect of the "food chain" of the NBIC products (need for comprehensive evaluation of societal implications)
  - global technological implications, cross-borders (connect models for governance at the national and the international levels);

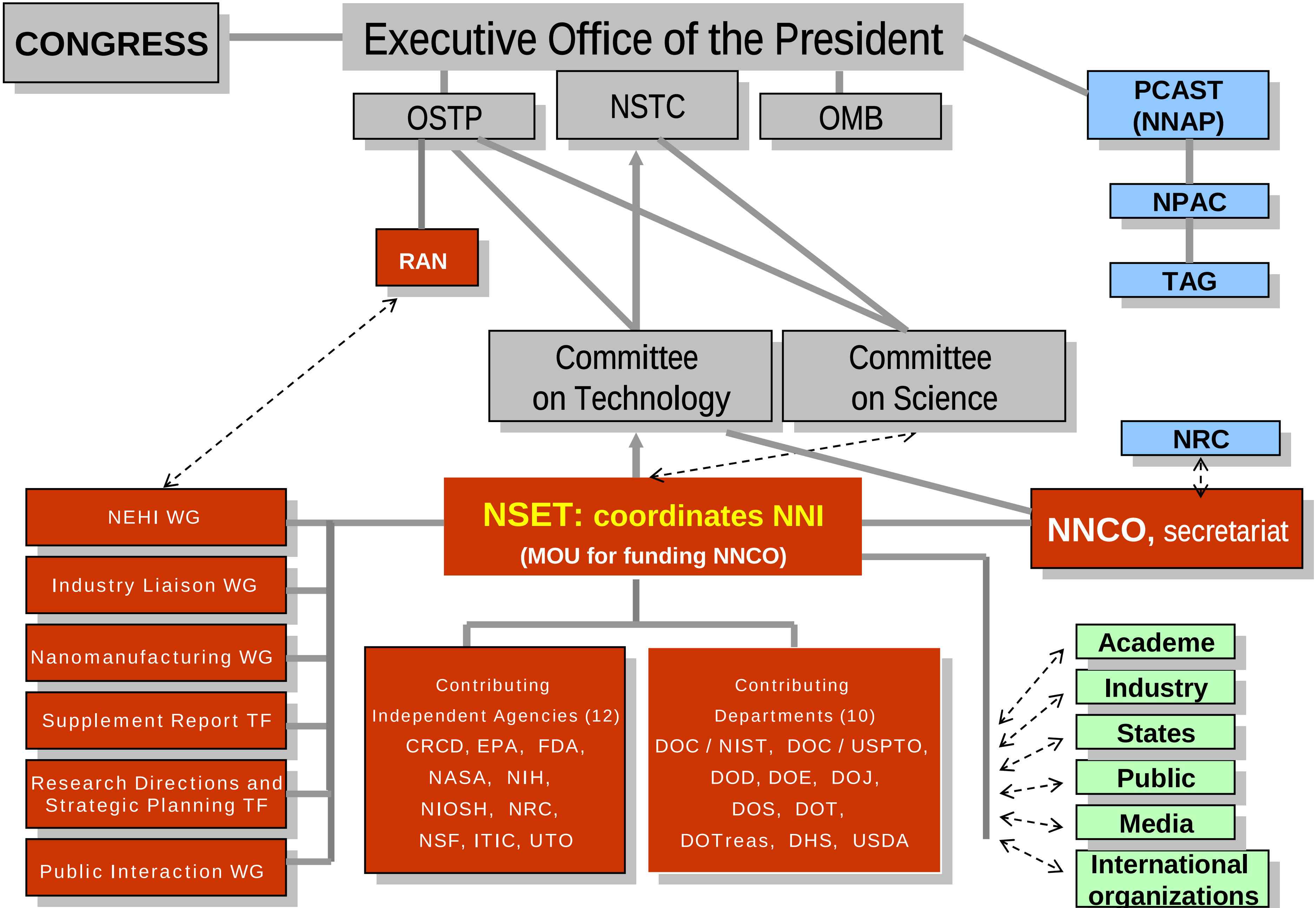
Sources of EHS risks in the societal system and nanotechnology risk governance



MC. Roco, 3/02/05

Governance of nanotechnology

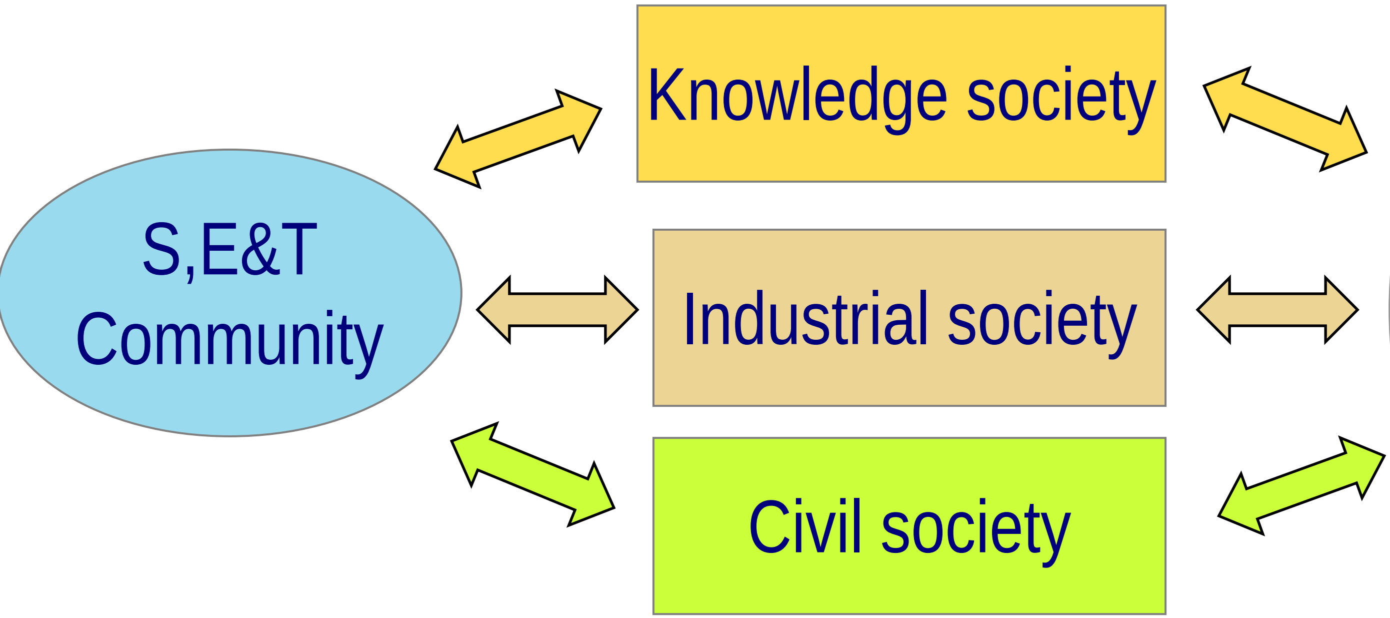
- Various national approaches to risk governance.
  Best models and approaches?
- Need for international coordination because the implications are global.
  Immediate issues: EHS, ELSI, education?
- Develop an international governance approach for nanotechnology (including East-West, North-South issues)?
  Role for International Risk Governance Council



Organization chart of the NNI

Grey: supervising organizations; Red: organizations implementing NNI;
Blue: organizations evaluating NNI; Dash lines: infromational links

NBIC community and societal interactions



UNINTENDED SOCIETAL IMPLICATIONS:

Secondary consequences and risks
(sample of issues)

- **Knowledge base**: creation of organisms? philosophical issues?

- **New technologies and products**: industry restructuring?

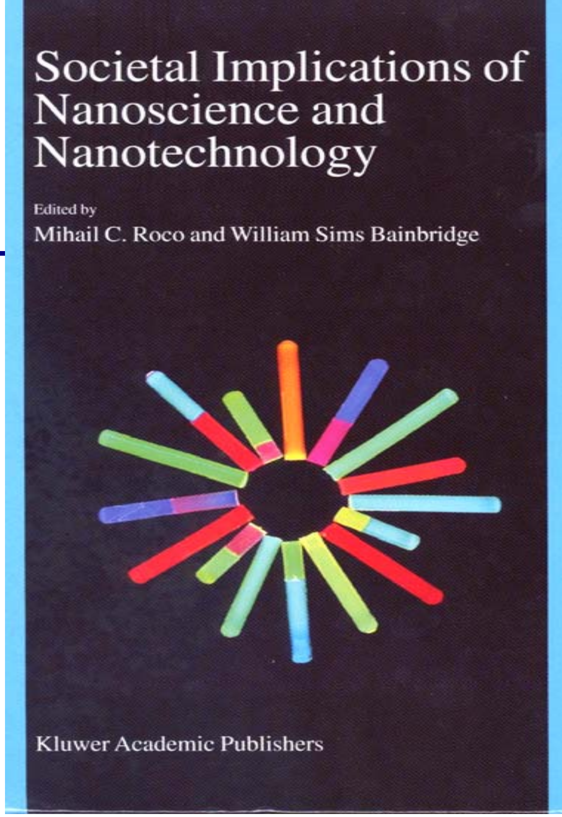
  Materials beyond chemistry: new material properties? safety?
  Electronics: society as an interconnected brain? privacy?
  Pharmaceuticals: secondary effects of medication? behavior control?
  Quality of life? New chemical manufacturing methods? . . . . .

  Changing jobs and organizations. Nano-divide?

- **Improved healthcare**: ethical and social issues? human dignity?

- **Sustainability**: impact of nanostructures on environment? cleaning existing contaminants? What is the new population limit for sustainable development with nanotechnology?

Societal Implications: Follow-up of the September 2000 report



http://nano.gov

- Make support for social, ethical, and economic research studies a priority:
  (a) New theme in the NSF program solicitations;
  (b) Centers with societal implications programs;
  (c) Initiative on the impact of technology, NBIC, HSD
- NNCO – communicate with the public and address Environmental, Health and and Safety issues, and unexpected consequences
- NSET's Nanostructures Environmental and Health Issues working group has been established in 8/2003, 12 agencies
- Workshop with EC (2001); Links to Europe, Americas, Asia; International Dialogue (26 countries, NSF-sponsored)

Key issues in long term

- Respect human right to: access to knowledge and welfare; human integrity, dignity, health and safety
- Balanced and equitable R&D nanotechnology investment
- Environment protection and improvement (water, air, soil) Sustainable development, life-cycle of products, global effects (weather), eliminate pollution at the source
- Economic, legal, ethical, moral, regulatory, social and international (developed-developing countries) aspects Interacting with the public and organizations
- Adaptive/corrective approach for a complex system

Immediate and continuing issues:

- *EHS in research laboratories and industrial units*
- *Harmonizing nomenclatures, norms and standards*
- *Primary data and methodology for risk analysis*

NNI activities
for Environmental, Health and other Societal Implications

A. Align R&D investment with societal implications

B. Evaluate and implement regulatory standards

C. Coordinated measures for EHS and ELES

D. Periodical meeting for grantees,
setting research targets, and
interaction with industry and the public

E. International collaboration (International Dialog
for Responsible R&D of Nanotechnology)

A. NNI coordination for R&D investments

- NSF research grants on environmental and societal implications
  All basic R&D areas, transport of nanoparticles; Programs since 2000
- NIH research on effects of nanoscale materials in the body
- EPA research grants on environmental implications of manufactured nanomaterials
- National Toxicology Program (NIEHS, NCTR, NIOSH)
  Project to study toxicity of nanotubes, quantum dots, and titanium dioxide
- NIST development of standards and measurements for nanoscale particles
- FDA and USPTO training and specialized activities
- USDA and DOE support fate and transport studies
- DOD supports exposure studies
- Solicitations (SI): NSF (ENV, SI), EPA-NSF-NIOSH, USDA, NIH

NSF environmental centers and interdisciplinary groups with research and education at the nanoscale

Center (details on www.nsf.gov/home/crssprgm/nano/nni01_03_env.htm)	**Institution**
Fundamental Studies of Nanoparticles Formation in Air Pollution	**Worcester Polytechnic Institute ($2.7M)**
Center for Advanced Materials for Water Purification	**University of Illinois at Urbana ($20.1M)**
Center for Environmentally Responsible Solvents and Processes	**University of North Carolina at Chapel Hill ($25.0M)**
Nanoscience in Biological and Environmental Engineering (estimated 50% in environment)	**Rice University ($11.8M)**
Environmental Molecular Science Institute	**Univ. of Notre Dame ($5M)**
NIRT: Investigating Nano-carbon Particles in the Atmosphere: Formation and Transformation	**University of Utah ($1.7M)**
NIRT: Nanoscale Processes in the Environment - Atmospheric Nanoparticles	**Harvard University ($1.6M)**
Center for Advanced Computational Environment	**SUNY Buffalo ($5.5M)**
NIRT: Nanoscale Sensing Device for Measuring the Supply of Iron to Phytoplankton in Marine Systems	**University of Maine ($0.9M)**

M.C. Roco, 3/03/05

NNI projects supporting toxicity research (examples)

Project	Agency, Institution
National Toxicology Program ($0.5M in FY 2004 to $5M in FY 2008)	NIH/NIEHS, FDA/NCTR, NIOSH
Particle characterization for health and safety ($1.7M in FY 2004 rto $2.3M in FY 2005)	NIOSH
Nanotechnology Characterization Laboratory ($5M/yr, part of $144M/yr NCI for FYs 2004-2008)	National Cancer Institute
Multidisciplinary University Research on Nanoparticle Toxicity	Department of Defense supported center
Molecular function at the Nano-Bio Interface (component on nanostructures and cell behavior)	NSF/NSEC U. Pennsylvania
Nanomanufacturing Center for Enabling Tools (component on safe manufacturing)	NSF/NSEC Northeastern University
Size Dependent Neural Translocation of Nanoparticles	NSF/SGER, Rochester University
Reverse Engineering Cellular Pathways from Human Cells Exposed to Nanomaterials	NSF/SGER

National Toxicology Program organization

NTP Director
Dr. K. Olden,
Dir NIEHS

Policy Oversight

Executive Committee	
ATSDR	NCI/NIH
CPSC	NIEHS/NIH
EPA	OD/NIH
FDA	NIOSH/CDC
NCEH/CDC	OSHA

Environmental Toxicology Program

External Science Oversight and Peer Review

Board of Scientific Counselors

Scientific Advisory Committee On Alternative Toxicological Methods

NIEHS

NCTR
National Center for Toxicological Research
U.S. Food and Drug Administration

NIOSH

Nanotechnology Characterization Laboratory (NCI) Concept of Operations

For comparison and characterization of nanomaterials intended for cancer detection, diagnostics, and therapeutics in humans.

Sources of <u>Nanomaterials</u>

- Cancer Centers of Nanotech Excellence (CCNEs)
- Academia
- NNI
- Small Business
- NCI, NIH, NSF
- DoD, DoE
- Unconventional Innovative Program (UIP)

NIST

NCL

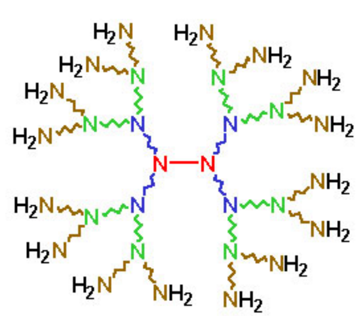
Physical Characterization

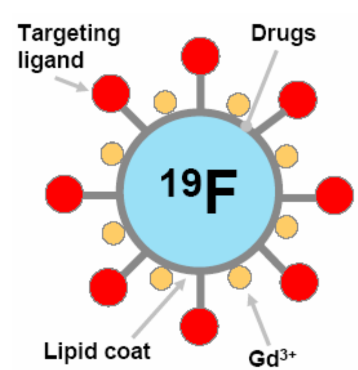
In Vitro

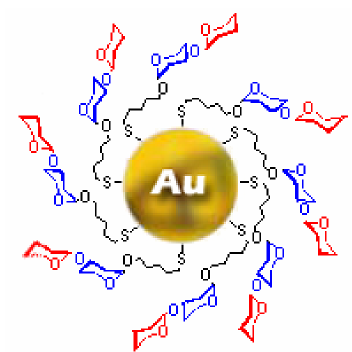
In Vivo

- Detection
- Diagnostics
- Therapeutics

Candidate Nanoparticles







MC Roco, 3/03/05

NNI projects supporting social implications (examples (1))

Project	Agency, Institution
Nanotechnology and its Publics	**NSF, Pennsylvania St. U.**
Public Information, and Deliberation in Nanoscience and Nanotechnology Policy (SGER)	**Interagency, North Carolina St. U.**
Social and Ethical Research and Education in Agrifood Nanotechnology (NIRT)	**NSF, Michigan St. U.**
From Laboratory to Society: Developing an Informed Approach to NSE (NIRT)	**NSF, U. of South Carolina**
Social and ethical dimensions of nanotechnology	**NSF, U. Of Virginia**
Ethics and belief inside the development of nanotechnology (CAREER)	**NSF, U. Of Virginia**
All centers, NNIN and NCN have a societal implications components	**NSF, DOE, DOD and NIH All nano centers and networks**

NNI projects supporting social implications (examples (2))

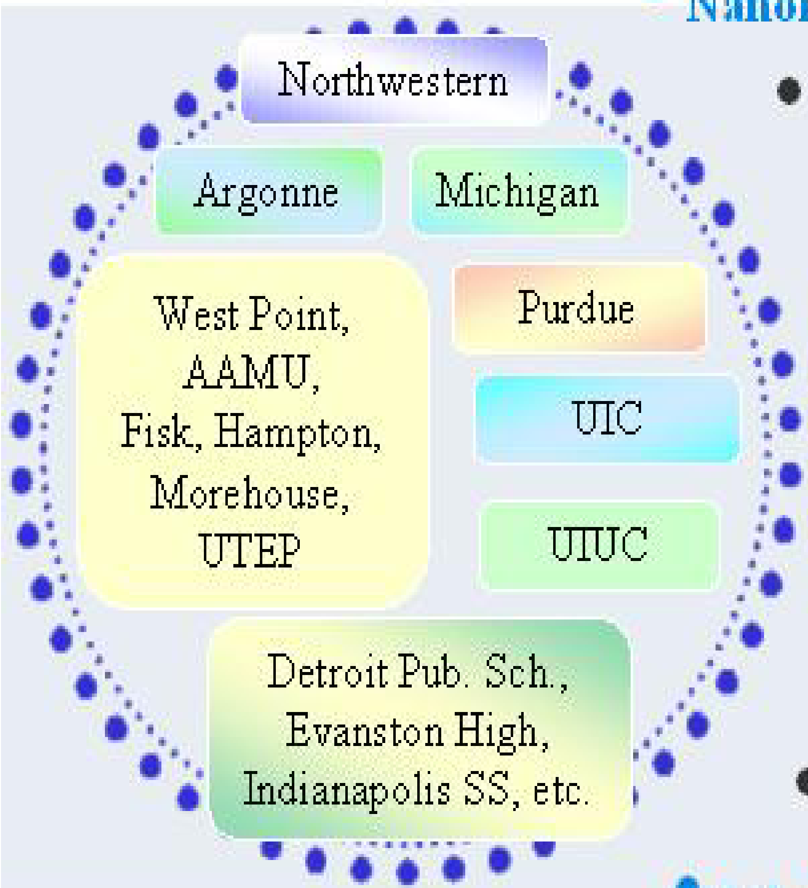
Project	Agency, Institution
Citizen Learning, Deliberation, and Reasoning in Internet-Mediated Technology Policy Forums	**NSF, North Carolina State University**
Public Information, and Deliberation in Nanoscience and Nanotechnology Policy (SGER)	**Interagency, North Carolina State University**
An Integrated Approach to Teaching Nanotechnology and Society (NUE)	**University of Wisconsin**
Nanotechnology: Content and Context (NUE)	**Rice University**
Undergraduate Exploration of Nanoscience, Applications and Societal Implications (NUE)	**NSF, Michigan Technological U.**
Assessing the Implications of Emerging Technologies (IGERT)	**NSF, MIT**
Nanoparticle Science and Engineering (IGERT)	**NSF, University of Minnesota**

Four NSF centers with national outreach fully or partially dedicated to societal dimensions

- Center for Nanotechnology in Society
  (2005 -)
- Nanotechnology Center Learning and Teaching
  (2004 -)
- Center for Nanotechnology Informal Science Education
  (2005 -)
- Center for Hierarchical Nanomanufacturing
  (2005 -)

Nanotechnology Center Learning and Teaching (2004 -)

The NCLT Community



- Nanomaterials Research: MRSEC, NSEC, DOE, NASA
- Curriculum Development: NSF-funded CCMS and MWM
- Education Research: NU-Searle Center, CCMS (led by AAAS)
- Professional Development: Summer programs on partner campuses, US-Minority Institutions
- Visualization & Learning Tools: EVL
- Simulation & Modeling: NCN
- School District Partnerships nationwide

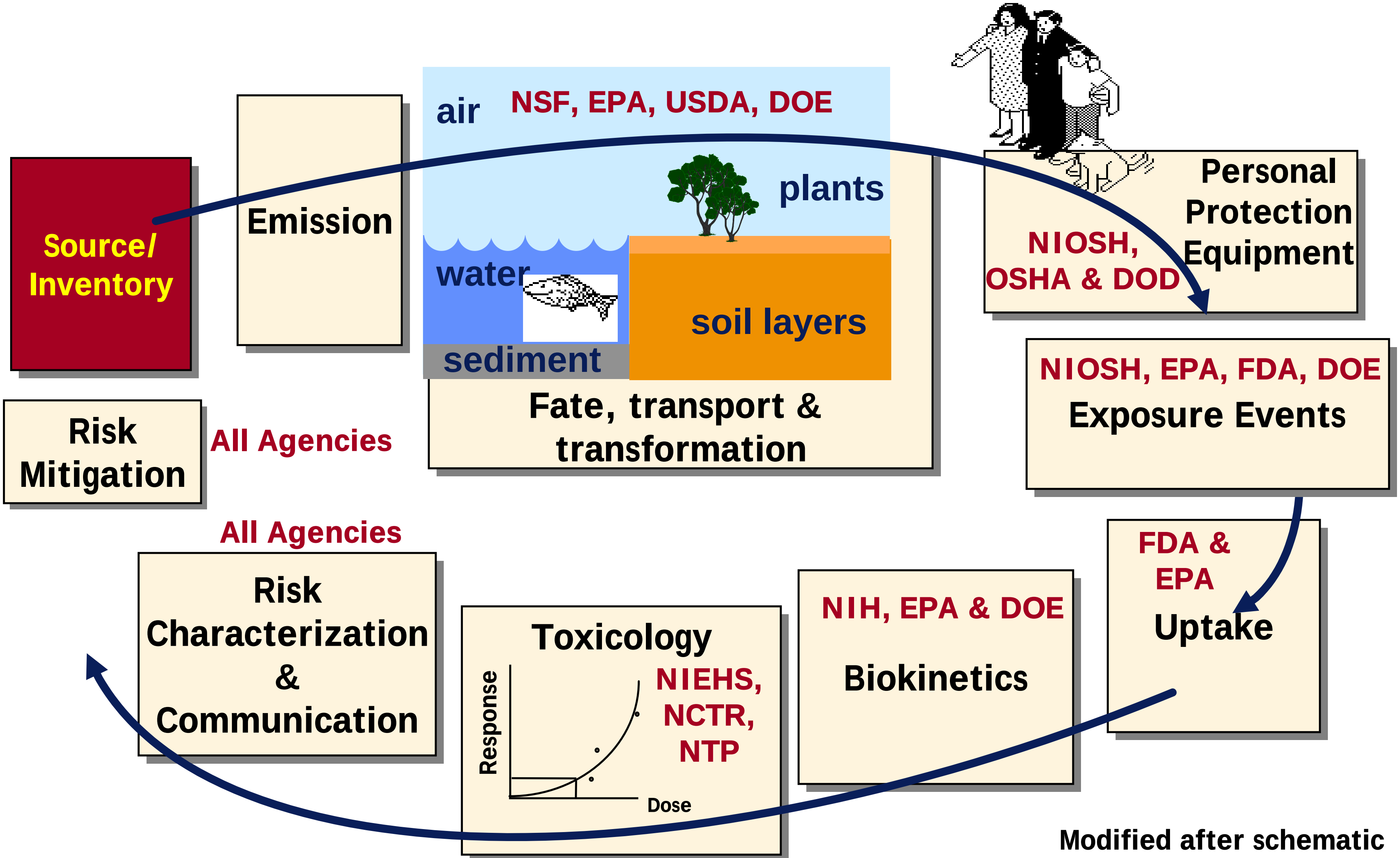
Estimation (by NSF) of NNI R&D funding for societal dimensions including contributions from all relevant multidisciplinary areas

First NNI Strategic Plan, FYs 2001-2005 (all budgets in $ million)

R&D supported by NNI agencies	FY 2001 (actual)	FY 2002 (actual)	FY 2003 (actual)	FY 2004 (actual)	FY 2005 (estimated)
1. ENV - basic R&D, implications and applic. (- excluding applications)	26.4 (9.0)	46.3 (13.6)	51.2 (17.0)	53.4 (25.4)	62.1 (27.6)
2. Health - basic R&D and implications	21.1	26.5	31.1	38.9	43.3
3. ELSI	0.4	0.9	3.4	5.5	7.4
4. Education - including contrib. fellowships (- excluding fellowships)	24.9 (6.0)	31.1 (7.2)	35.5 (8.2)	54.5 (11.7)	68.8 (22.2)
EHS (ENV + Health) + ELSI – Sum lines 1 + 2 + 3 above [% NNI budget]	**47.9 [10%]**	**73.7 [11%]**	**85.7 [10%]**	**97.8 [10%]**	**112.8 [10%]**
Societal and Educational Implications – Sum lines 1 + 2 + 3 + 4	72.8	104.8	114.2	152.3	181.6
Total NNI budget	***465***	***697***	***862***	***991***	***1031 + 150***

MC Roco, 3/03/05

B. Regulatory and Research Topics for EHS



Modified after schematic
Mark Alper, LBNL

C. Current NNI coordinated measures for EHS

- Develop statement on "Best practices" for research laboratories and industry units (NIOSH, NSF, DOE, NASA, DOD), and identify gaps
- Map of EHS responsibilities and contacts in each NNI agency
- Establish response approach to an unexpected event or an emergency
- Identify protective equipment suitable for nanoparticles and other nanostructured materials (OSHA, NIOSH, other agencies)
- Support development of instrumentation and metrology (NSF, NIST)
- Develop a unified, explicit nomenclature (agencies, ANSI)
- Develop standards for nanotechnology (NIST, ANSI, IEEE, ASME)
- Collaborative activities with industry (SRC, CCR, Phrma, IRI)
- Identify research and educational needs (Fundamental, GCs)

NSET Group: "Nanomaterials Environmental and Health Implications"

OSTP Group: "Risk Assessment of Nanotechnology" task force

Converging Technologies Bar Association (CTBA)

- Dialog with legal community
- Education and reference material for the legal system
- Source of information on implications of converging technologies form the nanoscale
- Public awareness
- Advocate policies, regulations and legislation. Anticipatory measures for the implications of NBIC
- Prepare reference materials and position papers

CBTA contacts for membership:

www.convergingtechnologies.org

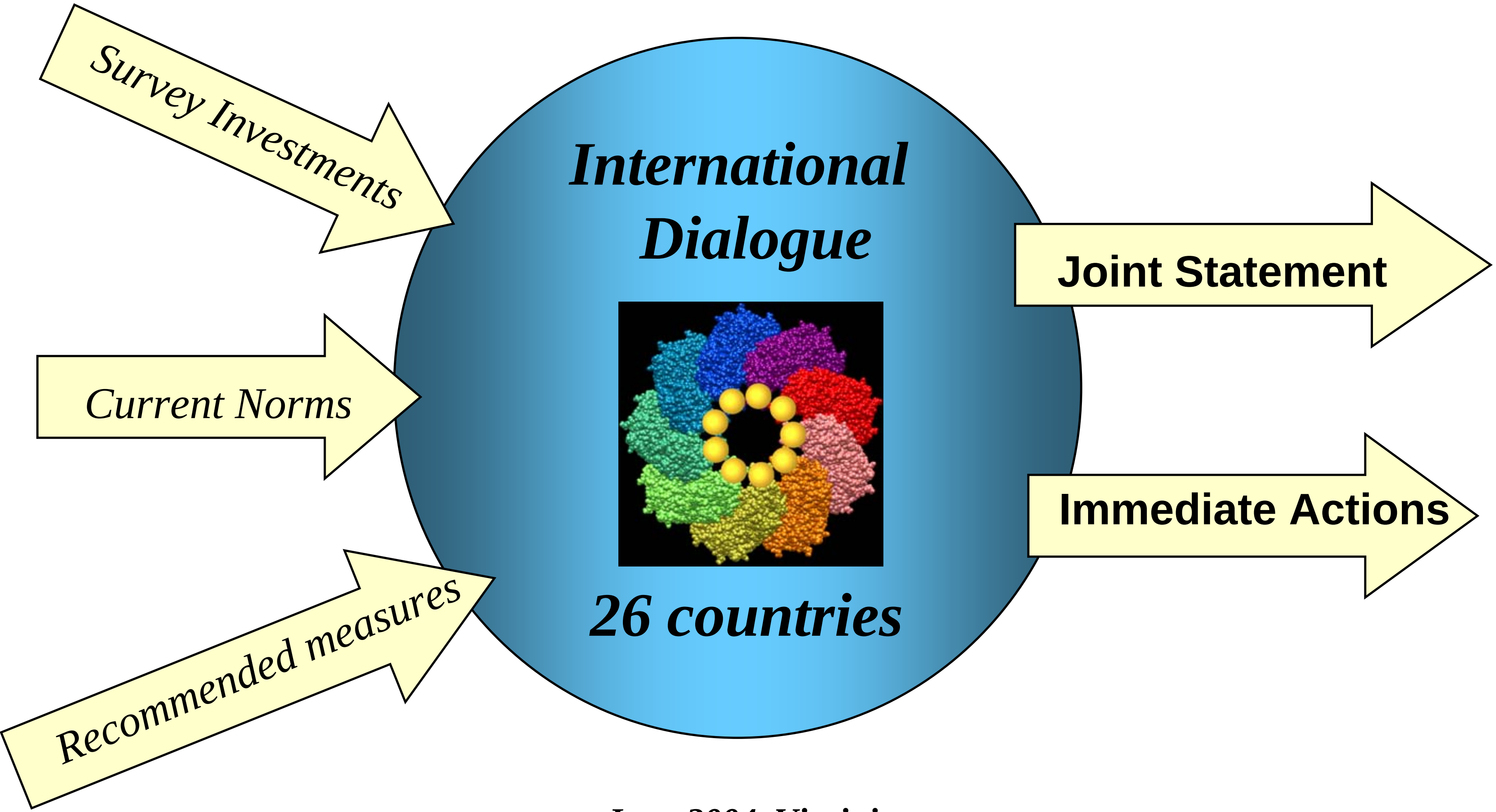
info@convergingtechnologies.org

D. NNI workshops on nano-environmental research

examples

- NSF, 9/2000: "Societal Implications of Nanoscience and Nanotechnology"
- NSF, 6/2002: "Nanoparticles and the environment"
  (grantees meeting, book)
- EPA, 11/2003: "Nanotechnology and the environment applications and implications" (grantees meeting, brochure)
- ACS, 3/2003: "Symposium on nanotechnology implications in the environment", New Orleans
- NNI, 5/2003: "Vision for environmental implications and improvement"
  (interagency, report)
- NSET/NNCO, 8/2003: Review of Federal Regulations (report)
- NNI, 9/2003: Interagency : grantees meeting (report);
- Wilson Center, 10/2003: EPA and FDA regulatory functions (report)
- NSET, 12/03 "Societal Implications of Nanoscience and Nanotechnology (II)"

E. International Dialogue on Responsible Nanotechnology R&D



June 2004, Virginia

http://www.nsf.gov/home/crssprgm/nano/dialog.htm

International Dialogue on Responsible Nanotechnology R&D

Activities after the June 2004 International Dialogue on Responsible Nanotechnology (Virginia, U.S.)

- **October 2004/October 2005 - Occupational Safety Group**
- **November 2004 – OECD group on nanotechnology**
- **December 2004 – Meridian study for developing countries begins (next meeting in March 2005)**
- **December 2004 - International collaboration for nomenclature and standards has been initiated**
- **February 2005 – N-S Dialogue on Nanotechnology (UNIDO)**
- **May 2005 – Nano-world, MRS (Materials, Education)**
- **Spring 2005 – International Agreement? (host: EC)**

North-South dialogue on nanotechnology

- Identify key application opportunities:
  healthcare, energy, water filtration, food, communication
- Identify suitable technologies:
  nano-biotechnology, solar cells, use local resources
- Develop partnerships:
  regional alliances, industry, international organizations
- Long-term view and plan of action:
  education, converging technologies, infrastructure, economy/jobs, human development, international interaction between developed and developing countries

Transforming and Responsible development of nanotechnology

<u>Reaching at the building blocks of matter</u> for all manmade and living systems, with the NBIC platform - makes transforming tools more powerful and unintended consequences more important than for other technologies

<u>Besides the immediate and continuing societal implication issues, a long-term concern is</u> <u>a possible instability in human development</u>, because perturbations created at the foundation of life and of the new transforming tools

<u>There is a need for an anticipatory and corrective approach</u> in

- planning, to be both transforming and responsible
- in addressing societal implications for each major R&D program or project from the beginning
- risk governance of converging new technologies at the national and international levels